CHAPTER 4: ENGINEERING ANALYSIS

The Engineering Analysis develops the relationship between the efficiency and cost of a central air conditioner or heat pump. This relationship serves as the basis for the subsequent cost-benefit calculations in terms of individual consumers, manufacturers, and the nation. Determining the cost-efficiency relationship involves analysis of the options available to manufacturers for increasing the efficiency of the baseline product (i.e, one that just meets the minimum efficiency standard.)

Residential central air conditioners are somewhat unique among the products regulated by the Department in that manufacturers: 1) structure their product lines around efficiency levels, 2) sell significant volumes of higher efficiency equipment, and 3) offer, or have studied, most of the design options available for increasing product efficiency. These characteristics make it possible to largely determine the cost-efficiency relationship for central air conditioners and heat pumps by examining actual products in the marketplace instead of estimating the cost and performance of design options using theoretical models.

The Department has chosen to take an efficiency level approach to this rulemaking. That is, analysis is performed in terms of product efficiency levels rather than design options. This method recognizes that manufacturers may use different paths to meet an efficiency requirement and estimates the cost of achieving the efficiency level without specifying precisely which path is taken. Therefore, the Engineering Analysis estimated equipment production costs at each potential efficiency level.

In addition to their effect on equipment production costs, higher efficiency standards can affect consumers by changing: 1) equipment prices, 2) installation costs, 3) maintenance costs, 4) repair costs, 5) product life, and 6) energy costs. The Engineering Analysis characterizes all of these potential effects.

The analysis of equipment production costs proceeded in two distinct phases—the validation analysis phase and the emerging technology analysis phase—as shown in Figure 4.1. The validation analysis phase (Section 4.2) included the tasks needed to determine the reasonableness of the cost data that the Air Conditioning and Refrigeration Institute (ARI) submitted to the Department. The emerging technology analysis phase then estimated the potential reduction in production costs due to the utilization of technologies that are currently under development but which have not been widely deployed.

For the validation analysis, the Department estimated the costs of producing equipment utilizing today's established technologies under new efficiency standards. Thus, each efficiency level analyzed assumed that new minimum efficiency standard was set at that level. The Department believes that current production costs for a higher efficiency product, say a 12 SEER air conditioner, would decrease if the minimum efficiency were raised to that level. Manufacturers of such products would have a greater incentive to cost-optimize their production at that level because of more intense competition and higher production volumes. ARI's guidelines to their members were to incorporate the same assumption regarding production at a new efficiency standard. However, some manufacturers might argue that costs of high-efficiency products may actually increase under new standards due to capital, engineering, and marketing costs incurred in converting to the new standard.

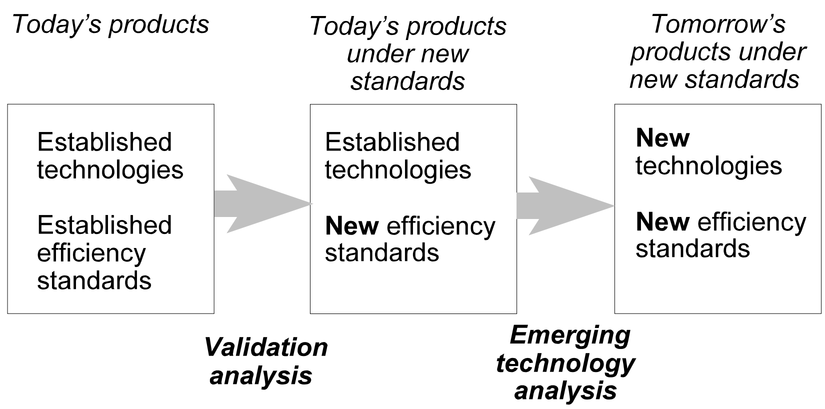

Figure 4.1 Phases of the Engineering Analysis

For the emerging technology analysis, the Department assessed the potential impacts of technologies that are currently under development on the production costs under new efficiency standards (Section 4.5). These include new technologies that have never been widely deployed and existing technologies that can benefit from further technological advance and economies of scale. The Department expects that these emerging technologies have the potential to lower the cost of improved efficiency.

In addition to quantifying manufacturing costs and the potential benefits of emerging technologies, this chapter includes the following subject areas:

- Markups (Section 4.3)
- Max Tech (Section 4.4)
- Product Classifications (Section 4.6)
- Alternative Refrigerants (Section 4.7)
- Relationship between HSPF and SEER (Section 4.8.1)
- Repair versus Replace (Section 4.8.2)
- Establishing an EER-based Standard (Section 4.9)

4.1 DESCRIPTION OF "BASELINE" UNIT

As mentioned in Chapter 2, NAECA defines four central air conditioning product classes: 1) split central air conditioning systems (cooling-only), 2) split central air conditioning heat pump systems, 3) single packaged central air conditioning systems (cooling-only), and 4) single packaged central air conditioning heat pump systems. Cooling efficiency is expressed as a Seasonal Energy Efficiency Rating (SEER) and heating efficiency is expressed as a Heating Seasonal Performance Factor (HSPF). NAECA requires products to achieve the minimum efficiencies listed in Table 4.1.

Table 4.1 NAECA Minimum Efficiencies for Single Phase Unitary Products 18,000 BTU/hr - 65,000 BTU/hr

	Split	Packaged
Cooling-only	10.0 SEER	9.7 SEER
Heat pump	10.0 SEER 6.8 HSPF	9.7 SEER 6.6 HSPF

More than 75 percent of equipment sold is rated at the minimum allowable efficiency.[1] [a] Products rated at the minimum efficiency level are termed *baseline*. They compete primarily on price and share similar physical characteristics. Although the efficiency level approach describes only the cost of the product at the minimum efficiency level (and higher efficiency levels) without reference to the underlying design or designs, the sample of baseline models selected for this analysis displayed the following similar characteristics:

- rifled copper tubes
- lanced aluminum fins
- single speed, single capacity compressor
- expansion orifice
- single speed permanent split capacitor (PSC) fan and blower motors

Equipment at higher efficiency levels may contain enhancements in one or more of these areas or may contain additional efficiency-related features such as variable speed control and time delay relays. Appendix B provides a more complete description of design choices displayed in our equipment samples.

[a] Numbered references refer to notes at end of the chapter

4.2 MANUFACTURING COSTS

Manufacturers routinely use reverse engineering to discover their competitors' designs, to evaluate the cost of adopting those designs themselves, and to attempt to avoid infringing on their competitor's patents. In the context of this Engineering Analysis, the term "reverse engineering" solely describes the estimation of production costs by examining actual equipment or designs. The ample examples of residential unitary equipment in the market provide the opportunity to use reverse engineering methods as the basis for estimating production costs. In this analysis, the production costs of 71 equipment models at eight efficiency levels were estimated, assuming each became baseline equipment under new efficiency standards. These production costs were normalized to the cost of their respective baseline costs, yielding relative costs analogous to ARI's relative costs. The cost multipliers were then compared to the ARI relative costs to help to identify any discrepancies and improve the underlying reverse engineering assumptions.

The production cost estimation process consisted of four tasks:

1. Selecting representative equipment
2. Describing equipment attributes
3. Modeling production processes
4. Determining the cost of materials, components, and assembly operations

Assumptions and data were based upon six sources of information:

- Interviews with manufacturers and suppliers
- Disassembly and analysis of equipment (tear down)
- Manufacturer data submittals
- ARI Product Attribute Database (proprietary)
- Published industry data
- Product literature

Table 4.2 illustrates the relationship between the information sources and the reverse engineering tasks.

4.2.1 Visits to Manufacturers and Component Suppliers

Between September and November 1998, DOE and ADL employees visited the facilities of 16 manufacturers and component suppliers and participated in presentations, interviews, and tours. Topics of discussion included product design, manufacturing methods, market dynamics, alternative refrigerants, product classifications, special issues related to heat pumps, and concerns related to new standards. Several visits also included tours of manufacturing facilities.

Table 4.2 Sources of Design Information

		Uses of Information			
		Equipment selection	**Description of product attributes**	**Process modeling**	**Component pricing**
Sources of Information	Manufacturer/supplier visits/interviews	✓		✓	✓
	Manufacturer data submissions		✓		
	Tear downs		✓	✓	
	ARI Attribute Data	✓	✓		
	Product Literature	✓	✓		✓

The visits served many purposes including gathering information concerning the Engineering Analysis, introducing company executives to the rulemaking process, and understanding the impact of a new standard on manufacturers. Ten of these meetings were conducted under an agreement of confidentiality, and the DOE employees did not retain written materials from any of the meetings. Meeting notes reside at ADL and are covered by separate non-disclosure agreements.

4.2.2 Selecting Representative Equipment

To select equipment samples for the reverse engineering analysis, we requested that manufacturers identify equipment in their product lines that would most nearly represent baseline equipment at each efficiency level through 17 SEER. For example, they named their current 12 SEER model that they would expect would be similar to the 12 SEER model under a 12 SEER standard. Manufacturers were also asked to describe the efficiency-related attributes of the products they selected. Four major manufacturers submitted design data for split cooling-only equipment, and three of those submitted design data for the other classes as well. This submission process yielded information on 62 models. We selected an additional nine models from catalogs of those and other manufacturers.[b] We also used the ARI Product Attribute Database (provided to our contractor under a non-disclosure agreement) and technical literature to describe the efficiency-related attributes in those products. Finally, from the group of manufacturer submittals, three units were purchased for extensive disassembly and inspection. Table 4.3 shows the breakdown of models examined.

Table 4.3 Breakdown of Equipment Subjected to Cost Estimation Analysis

	Models Examined	Tear Downs
Split Air Conditioner	32	1
Split Heat Pump	19	1
Packaged Air Conditioner	9	0
Packaged Heat Pump	11	1
Total	**71**	**3**

4.2.3 Disassembly and Inspection of Sample Equipment

One of the most effective methods for determining the production cost of a piece of equipment is to disassemble a sample and analyze it thoroughly. This process of disassembly and inspection is commonly called a *tear down*. Tear down identifies components, materials, and fabrication and assembly operations, and is the most accurate and precise method of estimating production cost short of obtaining the information directly from the manufacturers.

The three 3-ton models torn down were: 1) a 10 SEER split cooling-only condenser and evaporator combination, 2) a 10 SEER packaged heat pump, and 3) a 12 SEER split heat pump condenser. The 10 SEER tear downs were meticulous and provided comprehensive knowledge about those products. After disassembly, each part was identified, weighed, and described in detail. The 12 SEER tear down was less thorough since it was intended only to confirm the results of the cost estimates for the 12 SEER level.

[b] Catalog data were collected on two more models, but we eliminated the models from consideration when it was determined that their costs fell outside of the range of the costs bounded by manufacturer submissions. This ensured that the sample included only models with cost considered "representative" by manufacturers.

4.2.4 Modeling the Production Facility

From each detailed tear down, a structured bill-of-materials (BOM) was created. This structured BOM describes each part and its relationship to the other parts by the order of assembly. Each fabrication and assembly operation is described in detail, including the type of equipment used and the cycle time. The result is a thorough and explicit model of the production process. Visits to equipment plants and detailed discussions with a major supplier of plant equipment contributed to the assumptions regarding the production facility.

Two prototypical production facilities were created—a split system plant and a packaged system plant. Table 4.4 lists the specifications for each plant. Notice that the plants are greenfield facilities. "Greenfield" means that the facility is built new from the ground-up for the sole purpose of producing the equipment under analysis. This simplification suppresses differences among manufacturers and focuses on generic differences in plant and process that are related to efficiency. The results may, therefore, overestimate or underestimate the production costs of a particular manufacturer, but since they are calibrated to aggregate industry data, they should be accurate for the industry as a whole. Cost variability introduced by differences in manufacturers is handled separately as described in Appendix B . The Manufacturer Impact Analysis (Chapter 8) examines manufacturer variability in greater depth.

Table 4.4 Production Facility Specifications

Designed production capacity (split A/C) (units per year)	130,000	Production days per year	240
Actual production volume (split A/C and HP) (units per yr)	125,000	Fabrication shifts per day	2
Designed production capacity (pkg A/C and HP) (units per yr)	30,000	Hours per shift	8
Actual production volume (split HP, pkg A/C and HP) (units per yr)	25,000	Press lot size per day	1
Assembly line	Dedicated	Worker downtime	20%
Coil fabrication lines	Non-dedicated	Equipment downtime	10%

4.2.5 Compensating for the Commoditization Effect of Efficiency Standards on Baseline Equipment

Manufacturers must offer low-priced baseline products to attract price-sensitive home builders, dealers, and homeowners. Since price-sensitive purchasers are not willing to pay a great deal for added features, most baseline products possess only those attributes needed to meet minimum expectations of reliability and comfort. This emphasis on low price puts pressure on manufacturers to reduce production costs on baseline products. The pressure to reduce the production costs of higher efficiency products is not as great because those purchasers are less sensitive to price.

Since baseline products make up the majority of their production volume, manufacturers must consider this difference in cost reduction pressure between baseline and non-baseline products when seeking to optimize their production processes. Consequently, optimal production typically results in more cost-efficient production of baseline equipment and less cost-efficient production of non-baseline equipment.

As the efficiency standard rises, models that once exceeded the minimum efficiency level become the new baseline models. The Department assumes that commoditization of those products occurs as the market drives out premium products with added features in favor of lower price models. The elimination of features and the pricing pressures that result from more intense competition lower the cost of the product. The cost estimates in the reverse engineering analysis are based on these commoditized versions of today's higher efficiency equipment.

Two assumptions simulate the commoditization effect:

- Only those aspects of existing high-efficiency models that are essential for satisfactory operation and performance ratings were considered.
- Each model was assumed to be constructed and configured in the same way as the baseline equipment evaluated in the tear downs.

In effect, new baseline equipment were created at each efficiency level by substituting into today's 10 SEER baseline those efficiency-related attributes from today's higher efficiency equipment. Those efficiency-related attributes are listed in Table 4.5 along with the non-efficiency attributes that were not considered. The efficiency-related attributes that remained are significant. The analysis concluded that more than 95 percent of the cost of the baseline system was efficiency-related.

Table 4.5 Examples of Product Attributes Related to Efficiency

Efficiency-related Attributes	Non-efficiency Attributes
Coil features and dimensions	Noise suppression
Cabinet size	Aesthetic enhancement
Fin configuration	Serviceability enhancement
Compressor type	
Accumulator	
Controls	
Motor type	

The analysis did not consider the non-efficiency attributes listed for two reasons. First, the attributes were not observed in the baseline equipment samples, and pricing pressures will continue to prevent manufacturers from incorporating non-efficiency attributes into baseline equipment under new standards. Second, only those differences in incremental cost that relate to incremental efficiency affect the results of the consumer life cycle cost analysis.

Some may argue that one or more of the designated non-efficiency attributes are, in fact, tied to efficiency. For example, if higher efficiency products are inherently noisier, purchasers could require manufacturers to incorporate special noise suppression features even on their baseline equipment. If that were the case, the reverse engineering analysis would underestimate the cost of higher efficiency baseline equipment.

4.2.6 Estimating Parts, Assembly, and Overhead Costs

Parts were characterized based on whether manufacturers purchase them from outside suppliers or fabricate them in-house. For purchased parts, the purchase price was estimated. For fabricated parts, the price of intermediate materials (e.g. tube, sheet metal) and the cost of transforming them into finished parts was estimated. Whenever possible, ADL obtained price quotes directly from suppliers in volumes necessary to produce the equipment volumes shown in Table 4.4. For higher efficiency equipment, this assumption generally resulted in higher component purchase volumes and may have resulted in lower component prices than manufacturers currently pay.

After incorporating information on prices and manufacturing processes, estimates of labor rates, factory overhead, and indirect costs were added. For the most part, estimates were derived from generally available industry data. Table 4.6 lists the assumptions for those cost elements.

Table 4.6 Production Cost Assumptions

Direct labor rate	$13.33 per hr	Utility cost	21.6% of depreciation
Fringe	30% of wage	Maintenance cost	4% of depreciation
Indirect labor	50% of direct labor	Property tax	0.9% of revenues
Equipment Depreciation	1-20 years based on equipment type	Property insurance	0.8% of revenues
Building depreciation	30 years	Freight-in	3% of materials cost
		Freight-out	$1.66 per cubic foot

4.2.7 Generating Production Cost Results

All data were input into eight Microsoft Excel™ workbooks – two for each product class. One workbook in each pair is devoted specifically to estimating the cost of producing coils. The other estimates the cost of fabricating the remaining components and assembling the equipment. The workbooks contain proprietary and confidential information and are not publically available. More complete details of this methodology are presented in Appendix C.

The completed spreadsheets generated the production cost for each of the 71 models evaluated and the results were published in the Supplemental ANOPR and Preliminary TSD. Commenters generally supported the reverse engineering approach used to estimate the production costs of split air conditioners, several noted that heat pumps and packaged equipment received less rigorous treatment. The incremental production cost estimates for those three product classes were less consistent than were those for split air conditioners.

To address those concerns and shore-up the estimates for split heat pumps and packaged equipment, we applied "rules-of-thumb" suggested by Mr. Joseph Pietsch in an independent review. For systems of equivalent capacity and efficiency ratings, the guidelines are:

1. A split air conditioning fancoil system and cased coil system will share the same outdoor unit.
2. A split air conditioning fancoil system and split heat pump will share the same indoor unit.
3. A packaged air conditioner and packaged heat pump will share the same cabinet.
4. A split air conditioner and packaged air conditioner will share the same functional parts.
5. A split heat pump and packaged heat pump will share the same functional parts.

6. The cost differential between a split air conditioner with fancoil and a split heat pump, and a packaged air conditioner and a packaged heat pump, should be consistent across efficiency levels.

These guidelines are valid only for a particular manufacturer's product line and do not hold across product lines or across manufacturers. Since the reverse engineering equipment sample contained several manufacturers and product lines, applying these rules has the effect of minimizing any variability and bias introduced by the sample set. The approach also allows us to estimate the production costs of equipment at efficiency levels where we did not have any samples originally. We assessed only through 15 SEER to cover the range of relative cost estimates provided by ARI.

Figure 4.2 illustrates how the split air conditioner (cased coil) is used to derive the production cost estimates for the other products. At each stage, common costs are translated to the next product, and any missing costs are filled in using results from the original reverse engineering analysis described in the Preliminary TSD.

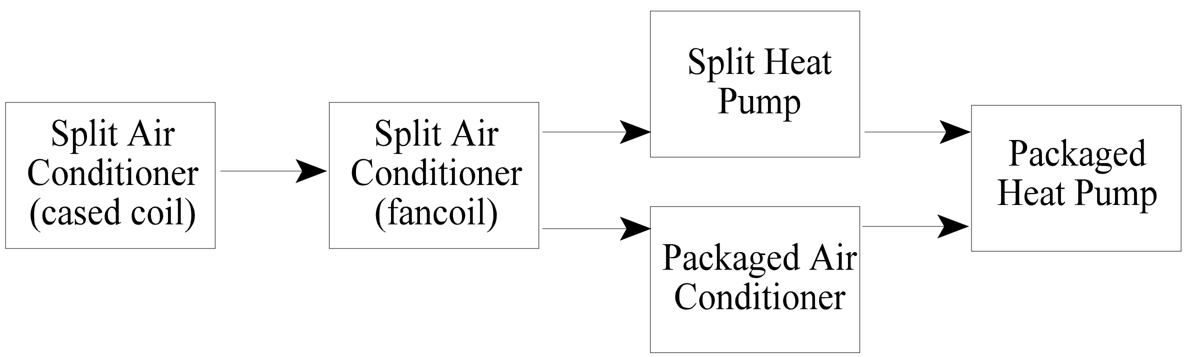

Figure 4.2 Relationship of Production Cost Estimates in New Reverse Engineering Approach

Table 4.7 provides the cost estimates resulting from this new approach. Results do not include any potential cost reduction due to emerging technologies, which are also under revision. Revised results are generally lower than the original results, particularly at the baseline 10 SEER level. The most significant change is that the new analysis includes nine additional estimates that were not presented in the Supplemental ANOPR and Preliminary TSD due to lack of data.

Table 4.7 Revised Reverse Engineering Production Cost Estimates for 3-ton Unitary Equipment

Efficiency Level (SEER)	Split Air Conditioner (cased coil)		Split Air Conditioner (fancoil)		Split Heat Pump		Packaged Air Conditioner		Packaged Heat Pump	
	Original	Revised	Original	Revised	Original	Revised	Original	Revised	Original	Revised
10	$367	$367	$456	$449	$622	$572	$552	$511	$643	$593
11	$412	$412	$550	$519	--	$602	--	$555	--	$638
12	$468	$468	--	$563	$690	$648	$627	$595	$708	$668
13	$529	$529	$756	$637	$840	$743	$809	$730	--	$820
14	$588	$588	$802	$815	$1,011	$1,023	--	$889	--	$1,029
15	--	--	$893	$893	$1,147	$1,107	--	$955	--	$1,100

Table 4.8 compares the results relative to the 10 SEER unit in each product class. Most revised results are similar to the original results presented in the Supplemental ANOPR and Preliminary TSD. The only significant departures are found in split air conditioners with fancoils, where the new estimates are lower, and in 14 SEER and 15 SEER equipment where the new results are higher.

Table 4.8 Revised Reverse Engineering Production Cost Multipliers for 3-ton Unitary Equipment

Efficiency Level (SEER)	Split Air Conditioner (cased coil)		Split Air Conditioner (fancoil)		Split Heat Pump		Packaged Air Conditioner		Packaged Heat Pump	
	Original	Revised	Original	Revised	Original	Revised	Original	Revised	Original	Revised
10	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
11	1.12	1.12	1.21	1.16	--	1.05	--	1.09	--	1.08
12	1.28	1.28	--	1.25	1.11	1.13	1.14	1.16	1.10	1.13
13	1.44	1.44	1.66	1.42	1.35	1.30	1.47	1.43	--	1.38
14	1.60	1.60	1.76	1.82	1.63	1.79	--	1.74	--	1.74
15	--	--	1.96	1.99	1.84	1.94	--	1.87	--	1.86

Appendix B provides the detailed cost estimates for each cost element for products at each efficiency level. The tables indicate which cost elements were derived directly from the reverse engineering analysis on those products and which were based on Mr. Peitsch's rules of thumb using costs estimated for other product classes.

4.2.8 Outbound Freight

Outbound freight is normally considered a sales expense and not a production cost. However, in the reverse engineering analysis, outbound freight charges scale as the size of equipment changes, so *outbound freight charges are included in the production cost results.* To avoid double-counting, outbound freight is later deducted from the recommended manufacturer markup (Section 4.3.2).

4.2.9 Industry Review

Although the cost-efficiency results are a suitable basis for subsequent analyses, the intent of reverse engineering methodology was to validate industry cost-efficiency projections and establish the absolute costs of present baseline equipment. This section describes that validation effort.

4.2.9.1 ARI Results

The Department and ARI agreed on a set of basic assumptions before ARI began collecting the data from its members. Each member who provided data to ARI estimated its own equipment cost under each new standard relative to its own current 10 SEER equipment. On March 13, 1999 ARI provided the aggregated results of this survey to the Department consisting of the mean, minimum, and maximum values at each efficiency level (11 SEER through 15 SEER) in each product class, all normalized to the baseline. Since each of ARI's members related its costs to its own baseline, each submittal had a baseline cost of 1.0. The aggregated curve, therefore, displays no variability in the baseline equipment.

To address the Department's question of whether the relative costs reflected the distribution of shipments, ARI received permission from its members to provide shipment weighted mean values. These data, which were provided to the Department on April 26, 1999, were based on 1998 manufacturer shipments and represent 90 percent of the total industry shipments.

4.2.9.2 Second ARI Review

On May 14, 1999 the Department presented the reverse engineering estimates to ARI for all four classes, having earlier reported results for split air conditioners only. ARI's members also received a prior version of the tables in Appendix B. The Department pointed out that significant and unexplained discrepancies still existed, and ARI agreed to review the results again. Certain manufacturers contacted the Department's contractor (Arthur D. Little, Inc.) to review the results and assumptions, and after several meetings with those manufacturers to identify and resolve apparent discrepancies, we finalized our original reverse engineering results.

4.2.10 Comparison Between Reverse Engineering and ARI Relative Costs

Table 4.9 compares the relative production costs provided by ARI with those developed in the reverse engineering analysis. These data show that as efficiency increases, ARI's mean relative production costs rise more rapidly than do the reverse engineering estimates. For split air conditioners, the difference is small through 12 SEER, but grows quickly above 12 SEER. For the other three classes, significant differences begin at 11 SEER. In all cases, the reverse engineering estimates match or exceed ARI's "minimum" relative costs.

The derivation of reverse engineering relative costs for the split air conditioner class is not straightforward since fancoil and cased coil units were evaluated separately. Eighty-four (84) percent of the split air conditioner samples through 13 SEER were cased coil units. At 14 SEER, 57 percent of the split air conditioner samples were cased coil. Over 14 SEER, there are no cased coil units represented in the sample set. The relative cost calculations paralleled that equipment selection. In Table 4.9, split air conditioner relative costs through 13 SEER represent the cost of cased coil systems relative to the cost of the average cost of a 10 SEER cased coil system. Relative split air conditioner costs for 15 SEER and above are fancoil system costs relative to the 10 SEER *fancoil system* cost. The 14 SEER split air conditioner relative cost represents the average of both the cased coil and fancoil costs relative to their respective 10 SEER counterparts.

Because the level of detail differs between the reverse engineering and ARI results, it is difficult to definitively identify the reasons for the discrepancies. Industry representatives have suggested that three aspects of the reverse engineering results significantly underestimate the incremental production costs of split air conditioners, and that the three aspects can explain most, if not all, of the discrepancy between the two sets of relative costs:

- Outdoor unit cabinet materials and labor
- Indoor coil materials
- Refrigerant

After reexamining those components and making adjustments, the reverse engineering results still fall below ARI's suggested values. ARI did not suggest improvements for split air conditioners over 14 SEER or for the other classes.

The Department believes that other factors may explain part of the remaining differences. These factors include:

- *Essential features* — "Essential" features are defined as any product attributes that are required to meet minimum standards of operation, performance, and reliability at a given efficiency rating. The Department assumes that baseline equipment sold under a higher efficiency standard will incorporate only essential features. Industry members might have defined essential features differently.

- *Metal prices* The reverse engineering analysis assumed flat 1998 prices, but some ARI members may assume higher prices more in line with historic averages.

- *R-22 prices* Although both the reverse engineering and ARI results are based on equipment charged with HCFC-22. Some ARI members may have assumed an inflation in HCFC-22 prices due to the EPA mandated HCFC-22 phaseout. The reverse engineering analysis assumed flat 1998 HCFC-22 prices.

- *Conversion costs* The reverse engineering analysis assumed that a generic manufacturer builds a modern production facility dedicated to producing equipment at only one efficiency level. Actual manufacturers may incur conversion costs that would result in increasing depreciation relative to increasing product cost.

- *Baseline costs* Manufacturers with similar incremental costs but different baseline costs will produce different relative cost curves. Therefore, the actual incremental costs contained in ARI's relative cost estimates cannot be determined without knowing their assumptions of baseline equipment cost. Thus, differences in baseline equipment cost could explain much of the variation in the ARI curves as well as disagreements with the reverse engineering-derived relative costs.

Uncertainty and variability also affect both sets of results. For example, the reverse engineering analysis was based primarily on a sample of models and design data submitted by manufacturers. It did not attempt to weigh the samples based on their representation in the marketplace. Also, some efficiency levels contained relatively few samples, increasing the uncertainty about whether those samples represent a "typical" model. These uncertainties could either raise or lower the reverse engineering estimates with respect to ARI's.

Table 4.9 Comparison of Revised Reverse Engineering Cost Estimates and ARI Relative Unitary Production Costs - 3-ton

		Standard Level (SEER)				
		11	12	13	14	15
Split Air Conditioners						
Rev Eng Most Likely[1]		1.12	1.28	1.44	1.68	1.96
ARI	Mean	1.16	1.36	1.63	2.03	2.40
	Min	1.03	1.09	1.30	1.60	1.81
	Max	1.30	1.55	1.90	3.00	3.50
Split Heat Pumps						
Rev Eng Most Likely		1.05	1.13	1.30	1.79	1.94
ARI	Mean	1.10	1.24	1.44	1.64	2.09
	Min	1.05	1.11	1.17	1.30	1.75
	Max	1.15	1.35	1.66	1.88	2.52
Packaged Air Conditioners						
Rev Eng Most Likely		1.09	1.16	1.43	1.74	1.87
ARI	Mean	1.19	1.30	1.63	1.87	2.23
	Min	1.03	1.15	1.40	1.59	1.89
	Max	1.27	1.40	1.75	2.00	2.92
Packaged Heat Pumps						
Rev Eng Most Likely		1.08	1.13	1.38	1.74	1.86
ARI	Mean	1.14	1.28	1.60	1.75	2.13
	Min	1.06	1.06	1.45	1.65	1.93
	Max	1.25	1.50	1.90	2.30	2.47

“Cost of 1.0 represents base cost for 10 SEER for split systems and 9.7 SEER packaged systems

[1] 11 SEER - 13 SEER based on cased coil only, with respect to the 10 SEER cased coil system cost. 15 SEER based on fancoil only with respect to the 10 SEER fancoil system cost. 14 SEER represents the mean of relative cased coil and fancoil system costs with respect to their 10 SEER baselines.

4.2.11 Validation of ARI Results

In all cases, ARI's mean production cost multipliers exceed those from the reverse engineering analysis. However, the reverse engineering cost model cannot replicate many of ARI's maximum values. Also, the analysis cannot explain the wide range between ARI's minimum and maximum values at the higher efficiency levels. This result seems to conflict with the premise that new standards will force high-efficiency products to compete on price and keep products within the same price variation as current baseline equipment. Without further explanation from ARI as to the assumptions behind their maximum values, the reverse engineering analysis cannot validate ARI's results completely.

4.3 MARKUPS

The Life Cycle Cost Analysis requires among its inputs 1) the price consumers pay for baseline equipment, and 2) the incremental prices they must pay to purchase higher efficiency levels equipment assuming efficiency standards set at those levels. For the water heater and ballast rulemakings, the Department relied on market surveys to determine retail prices and has applied relative cost-efficiency curves to determine incremental prices. That approach works well for appliances that consumers can purchase directly since retail prices are easy to ascertain. However, in the central air conditioning market, dealers sell equipment as part of an installation package and do not list retail equipment prices separately from installation cost. Furthermore, differences in local markets, weather conditions, demand, and many other factors can all affect the price contractors charge for air conditioning equipment.

As an alternative to the retail price survey, the Department determined typical markups along the distribution chain from the manufacturer through the consumer. We also used this approach in the clothes washer rulemaking. The markup approach makes it possible to estimate a retail price from the manufacturing cost. Representative markups were determined from the top-down using publicly available corporate and industry data. This approach is transparent and avoids the confusing and largely irrelevant differences with which a survey must contend. However, because it depends on high level information, it risks overlooking details that are important to the analysis.

4.3.1 Description of Distribution Chain

Most residential central air conditioning equipment passes through a two-step distribution chain: 1) manufacturer to distributor (or wholesaler), and 2) distributor to dealer (or contractor). Lennox uses one-step distribution (manufacturer to dealer) for its Lennox-brand products and is the only notable exception. Large retailers (Sears, Home Depot) replace the distributor in the chain for some manufacturers.

Roughly two dozen equipment manufacturers, several hundred distributors, and more than 30,000 dealers operate in the United States. Due to a wave of consolidation over the last 15 years, the top seven manufacturers control 97 percent of the market share. Most remaining small manufacturers produce only indoor coils or niche product lines.

Equipment manufacturers sell most of their products directly to distributors (also called wholesalers.) Distributors sell to dealers at the distributor (wholesale) price. Distributors absorb short-term imbalances in supply and demand, allowing manufacturers to operate more efficiently and satisfying consumer needs for fast deliveries. Distributors may specialize in HVAC equipment or may deal in other products. They are also important sources for after-market parts that boost margins. Distributors compete on price and service, although geographic boundaries and relationships prevent margins from being squeezed to commodity levels.

Most dealers compete at the local level. Many carry more than one brand, and most install the products they sell. Some are engaged in other contracting business, and most do commercial work. Dealers are consolidating rapidly in the wake of similar trends at the wholesale and manufacturer levels. There are now several large, national, publicly traded air conditioning dealers. Lennox has also acquired dealers to complement its vertical integration of its distribution channels.

At each point in the distribution chain, companies mark up the price of the equipment to cover their business costs and profit margin. In financial statements, *gross margin* is the effective markup on a company's cost of sales. It includes all corporate overhead costs; sales, general, and administration (SG&A); research and development (R&D) and interest expenses; depreciation and taxes; and profits. In order for sales of a product to contribute positively to company cash flow, its markup must be greater than the corporate gross margin less the company's operating profit margin. Individual products may command a lower or higher markup depending on their perceived added value and the competition they face. The Department generally assumes that gross margins on baseline residential unitary equipment are lower than the average gross margin of a diversified company.

4.3.2 Determination of the Manufacturer Markup

Publicly held corporations file annual reports (10-Ks) with the Securities and Exchange Commission (SEC). There are six sets of 10-K reports for the six publicly traded air conditioner manufacturers (listed in Table 4.10 as Mfr. A – Mfr. F). Two of the manufacturers listed have since merged. The six sets of reports served as the basis for the estimation of the manufacturer markup. The companies represented account for about 85 percent of the unitary market. Manufacturers D, E, and F engage substantially in business other than the production of air conditioning equipment. Manufacturer F engages substantially in business not related to building equipment. All companies sell products other than residential unitary air conditioners, including furnaces, commercial air conditioners, and after market parts. Many of these other products command higher margins than do baseline air conditioners.

Of the six public companies, Manufacturers A and B are most dependent on residential unitary sales, and we expect their financial statement to be most indicative of the cost structure associated with the production and sale of residential unitary equipment. Manufacturer C, because it is also engaged solely in the air conditioning business, is also a good example. Manufacturer A's five year average is adversely affected by extraordinary restructuring charges in 1995. Manufacturer B's gross margin is substantially higher than that of its competing firms. The others best represent typical markups on building products in general.

Table 4.10 lists the corporate gross margin, gross margin adjusted for baseline equipment, and corresponding markups for each of the six manufacturers. Each firm's profit margin (EBIT, Earnings Before Interest and Taxes) is replaced with a 2 percent figure to simulate the margin on a baseline unit. Actual margins may be higher, particularly for firms who specialize in the production and sale of baseline equipment. Outbound freight was also deducted since it is already included it in the reverse engineering cost estimates (see Section 4.2.8). Except where noted, figures are listed for 1997 as well as the averages over the preceding four years.

Table 4.10 Manufacturer Gross Margins and Markups

	Year(s)	Mfr A	Mfr B	Mfr C	Mfr D	Mfr E	Mfr F
Fraction of revenues related to space conditioning products	1997	100%	100%	100%	25%	60%	25%
Corporate gross margin	1997 1993-97	20.1% 17.4%	35.3% (1999)	19.9% 21.0%	26.7% 27.7%	26.7% 27.7%	24.5% 24.0%
Gross margin with 2% EBIT	1997 1993-97	18.6% 20.6%	33.1% (1999)	19.4% 19.5%	24.9% 25.5%	24.9% 25.5%	19.4% 20.1%
Markup	1997 1993-97	1.23 1.26	1.49 (1999)	1.24 1.24	1.33 1.34	1.33 1.34	1.24 1.25
Markup (less freight-out)	1997 1993-97	1.17 1.20	1.43 (1999)	1.18 1.18	1.25 1.26	1.27 1.28	1.18 1.19

Sources: SEC 10-K reports (1993-1997), 10-Q report (4Q1999)

The Department selected a representative manufacturer markup of 1.23 for use in estimating the price of baseline equipment. This represents a weighted average of Mfr B's and Mfr C's calculated markups assuming a 20 percent / 80 percent ratio, respectively.

4.3.3 Determination of Distributor Markup

Table 4.11 lists the median 1997 gross margin for 14 members of the Air Conditioning and Refrigeration Wholesalers (ARW) engaged in the sale of air conditioning and heating equipment.

Table 4.11 Distributor Median Gross Margins and Markups

Gross margin	1997 1993-97	27.0% 26.9%
Markup	1997 1993-97	1.37 1.37

Source: *1998 Wholesaler PROFIT Survey Report*, Air Conditioning and Refrigeration

The indicated markup of 1.37 represents the typical markup applied to products sold in the base case. As the cost of an air conditioner increases, we would expect that the markup on the price difference to be less than the average markup since only a fraction of the distributor's costs scale with the unit cost of materials.

To determine what the markup on the incremental price difference might be, we examined the ARW financial reports in closer detail, identifying the financial components that we would expect to scale with prices changes. The markup suggested by that analysis is 1.11. An examination of U.S. Census data suggested a value of 1.09. A wide uncertainty band exists around both of these results, but they are much lower than the average markup of 1.37.

Since the statistical evidence provided a probability distribution, we used those results to represent the distributor markup on the incremental portion of equipment costs. The basic portion of equipment costs we assume continues to be marked up at the average value of 1.37. Table 4.12 provides the mean combined markup at each standard level considered.

Table 4.12 Distributor Markups used in the Analysis for each Standard Level

Standard Level	Markup
10 SEER	1.37
11 SEER	1.33
12 SEER	1.30
13 SEER	1.26

Appendix D presents the detailed derivation of the distributor markups.

4.3.4 Determination of Builder Markup

In new construction, the builder marks up the cost of the property, including the air conditioning equipment. Based on gross margins estimated by Dunn and Bradstreet[2] and Risk Management Associates (formerly Robert Morris Associates)[3], we chose to apply a uniform range of markups from 1.20 to 1.32 to the 34 percent of air conditioners and heat pumps that find their way into new construction. That yields a weighted average markup new and existing construction together of 1.09. In all cases, we assume that builders purchase their equipment from distributors rather than directly from the manufacturer.

4.3.5 Determination of Dealer Markup

Dealers, or contractors, sell equipment to consumers at the dealer price. However, since the dealer also install the system, the purchaser typically pays an installed price that includes all labor, materials, and markups required to install the equipment. This flat rate pricing hides the actual dealer price of the equipment.

Just as with the distributor markup, we estimated the average equipment markup on baseline equipment, and the markup on changes in the unit cost of the equipment. Analysis of financial reports published by the Air Conditioning Contractors of America (ACCA)[4] suggests that the average markup on all costs, including labor, for residential air conditioning contractors varies between 1.41 for new construction and 1.63 for retrofit and replacement, for an overall average of 1.55. However, closer examination of the financial statements suggest that the average contractor markup on equipment only is closer to 1.28. Examination of U.S. Census Bureau data suggests that both the average and the marginal markup are 1.27. Details of these analysis are described in Appendix D.

Since the statistical analysis provides a range of dealer markups, we chose to use it in the analysis. Thus, we applied a mean dealer markup of 1.27 to all product classes at all standard levels.

4.3.6 Determination of Sales Tax

In many cases, local and state governments apply sales taxes to air conditioner purchases. The sales tax applied to the dealer price yields the retail price paid by the consumer. Table 4.13 lists the cumulative and shipment-weighted sales tax rates based on 1997 state sales tax data[5], 1997 local sales tax data[6], and 1994 state unitary shipment data[7]. The mean sales tax rate is 6.7 percent, corresponding to a markup of 1.07. We adopted this distribution for the sales tax paid, except for the 34 percent of units sold into the new construction market. In those cases, we assumed that purchasers pay no sales tax on the equipment. This is equivalent to a weighted average sales tax for all products of 1.04.

Table 4.13 Distribution of 1994 Unitary Shipments at Various Sales Tax Rates

Combined Sales Tax Rate (nearest whole percent)	0%	5%	6%	7%	8%	10%
Fraction of Shipments	1%	10%	29%	37%	22%	1%

4.3.7 Overall Markup

Overall markups applied to baseline equipment result from combining the manufacturer, distributor, builder, dealer, and sales tax markups at each efficiency level. They range from 2.42 under a 10 SEER standard down to 2.23 under a 13 SEER standard. Table 4.14 summarizes the results. These markups are valid only when outbound freight is considered a production cost (Section 4.2.8).

Table 4.14 Average Markups on Baseline Residential Air Conditioners

Manufacturer Markup	1.23
Wholesaler/Distributor	
10 SEER	1.37
11 SEER	1.33
12 SEER	1.30
13 SEER	1.26
Dealer/Contractor	1.27
Builder Markup	1.09
Sales Tax	1.04
Overall Markup	
10 SEER	2.42
11 SEER	2.35
12 SEER	2.30
13 SEER	2.23

4.4 MAX TECH

The highest efficiency level that is "technologically feasible" is known as "Max Tech." A product can be technologically feasible without being either commercially practical or economically justified.

Based on a limited assessment of thermodynamic limitations and potential system improvements, the Department estimates that the highest technologically feasible level for 3-ton air conditioners is 30 EER, but that equipment is not commercially practical. The highest commercially practical efficiency level is estimated to be nearly 16 EER, or 20 SEER. Thus, the Department is proposing to eliminate from consideration any potential standard level that exceeds a 20 SEER rating as not commercially practical, and therefore, not economically justified. Furthermore, since we are not aware of any prototype or production unit that exceeds, or has ever exceeded, 18 SEER, we are considering 18 SEER to be the Max Tech level. Some niche products and all coil-only products have a Max Tech that is considerably lower.

We did not estimate the cost of all equipment through 18 SEER, but are confident that their costs exceed those of the highest efficiency products we evaluated. For example, the cost of a 18 SEER split air conditioner is expected to cost at least as much to produce as a 15 SEER split air conditioner.

The remainder of this section examines in more detail the factors that determine Max Tech and the highest efficiency level that is commercially practical.

4.4.1 The Vapor Compression Cycle

Conventional air conditioners utilize a thermodynamic cycle known as the *vapor-compression* cycle to cool interior air and reject the heat to exterior air. (In heating mode, heat pumps operate the cycle in reverse, cooling the exterior air and heating the interior air.) Heat is transferred between the interior and exterior air using a intermediate refrigerant–usually HCFC-22. The refrigerant passes through the tubes in tube-and-fin heat exchanger "coils" as air passes over the fins.

Within the air conditioner, cold refrigerant gas accepts heat in the evaporator and rejects it in the condenser.[c] A compressor pumps refrigerant to the condenser, raising its temperature and pressure in the process. In the condenser, the hot gas rejects heat to the outside air and condenses into a liquid. After leaving the condenser, the liquid refrigerant passes through an orifice or expansion valve and returns to the evaporator at a lower pressure. In the evaporator, the cold gas accepts heat from the indoor air. Some of the heat comes from water vapor (humidity) as it condenses on the evaporator coil.

[c] In heat pumps, the role of the condenser and evaporator reverses in the heating mode, but the names remain the same.

4.4.2 Technically Feasible Efficiencies

Technical feasibility implies that a system is not only theoretically possible, but is capable of being designed, constructed, and operated. A technically feasible system may be quite costly or may exceed constraints such as size or comfort and may, therefore, not be commercially practical.

4.4.2.1 Carnot Efficiency

The ideal efficiency of a vapor compressor cycle can be expressed in terms of its comparison to the efficiency of a Carnot cycle. The Carnot cycle is an ideal cycle because it is perfectly reversible. It is impossible for real equipment to achieve Carnot efficiency because real processes are not reversible. For the EER test, the outdoor and indoor air temperatures are 95°F and 80°F respectively. The efficiency of a Carnot cycle operated under those conditions is 123 EER.[d] However, in practice, the requirement for dehumidification lowers the evaporator temperature. Assuming that the air conditioner is designed to lower the indoor wet bulb temperature from 67°F to 62°F, both at a 77°F indoor dry bulb temperature, the evaporator must cool the indoor air to its dew point temperature of 52°F. The efficiency of a Carnot cycle operating between 52°F and 95°F is 41 EER. It is theoretically, but not technically, possible to build a system that approaches this efficiency rating.

4.4.2.2 Practical Barriers to Carnot Cycle Equipment

The use of an expansion valve or orifice in conventional air conditioners results in superheated vapor that must be returned to a liquid in the condenser. A Carnot system would replace the expansion device with a turbine or other mechanical expander that could generate power as the refrigerant expands. The power generated would then be used to power the compressor. The Carnot system also would use another compressor to raise the pressure of the refrigerant to its saturation pressure before it reaches the condenser. The added cost and maintenance associated with the extra compressor and power transmission equipment is prohibitive for residential applications. Furthermore, each piece of real equipment would contribute inefficiencies that would reduce the overall effectiveness of the system.

4.4.2.3 Irreversibilities

As an ideal cycle, the Carnot cycle is comprised of a set of perfectly reversible processes. Real cycles, on the other hand, contain several imperfections that result in irreversible processes. These include:

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[d] The formula for determining First Law efficiency in EER is $3.412 * T_L/(T_H-T_L)$ where T_L and T_H are the lowest and highest temperatures in the system in Rankine (0°F = 460 R).

- Pressure drops due to fluid friction as the refrigerant and lubricant flows through the system
- Transfer of heat to the environment at points other than the heat exchangers
- Inefficient compression and expansion due to friction heating and heat transfer between the refrigerant and the compressor or expansion valve
- Compressor motor inefficiency and transfer of heat from the compressor motor to the refrigerant

The *1997 ASHRAE Handbook– Fundamentals* (F-1.13) gives some relative values for sources of irreversibility in a 2-ton refrigeration system operating between the temperatures of 20°F and 90°F (Table 4.15).

Table 4.15 Sources of Irreversibility in a Conventional Refrigerator

Component	Fraction of Total Irreversibility (%)
Evaporator	19
Suction Line	4
Compressor	32
Discharge Line	6
Condenser	17
Liquid Line	0
Expansion Device	23

Source: 1997 ASHRAE Handbook

There is also significant irreversibility associated with the transfer of heat at the heat exchangers. The Carnot cycle assumes that there is no temperature difference between the heat exchangers and their surroundings. For this to be possible, the heat exchanger surfaces have to be infinitely large or the heat transfer coefficient would have to be infinitely high.

4.4.2.4 Practical Barriers to Eliminating Irreversibilities

Manufacturers can do several things to reduce irreversibilities, but because of various thermodynamic and operating constraints, they cannot eliminate them altogether:

- Actual systems must maintain a high enough temperature difference between the refrigerant and the air to result in sufficient heat transfer within a finite space. The smaller the heat transfer surface, the higher the required temperature difference. The impact of this constraint is significant. For example, a temperature difference of 25°F at the condenser and 10°F at the evaporator reduces the maximum attainable cycle efficiency to 22 EER.

- Refrigerant velocities in actual systems must be high enough to entrain the compressor lubricant and return it to compressor. This limits tube diameters and results in unavoidable drops in pressure.

- Cost, size, weight, and maintenance considerations all prevent the substitution of a mechanical expander for the expansion device in conventional residential systems. However, such a substitution is technically feasible.

- Insulation of lines and components can be highly effective, but would have only a slight impact on system efficiency. Cost is the primary constraint, although a highly insulated system is technically feasible.

- Clearances in the compressor can be reduced to lessen internal circulation between high and low pressure zones. This is technically feasible to a point, but increases cost.

4.4.2.5 Parasitics

Electric power consumed by components other than the compressor are called parasitics. Equipment parasitics consume system power and affect system EER and SEER ratings, but are not accounted for in the calculation of the vapor-compression cycle efficiency. Fan motors are the most significant of these. Controls are another example. Parasitic requirements can account for up to 25 percent of the power consumed in a conventional residential air conditioner.

4.4.2.6 Practical Barriers to Eliminating Parasitic Losses

Again, manufacturers have a few options for reducing parasitic losses, but they cannot eliminate them:

- Fan power can be reduced by improving fan aerodynamics, increasing motor efficiency, and improving air flow in the equipment cabinet. Aerodynamic and airflow improvements typically signify slower, larger fans and contoured cabinets. Size and cost are primary considerations, although significant improvements over conventional systems are technically feasible.

- Heat exchangers can be designed that impose less air resistence also reduce fan power (e.g. tubes without fins). However, they may reduce the coil's ability to effectively transfer heat and cause a countervailing increase in compressor power.

Still, coil designs that are capable of reducing air resistence while maintaining coil effectiveness are technically feasible.

4.4.2.7 Max Tech

Starting with a theoretical efficiency of 41 EER, and assuming that parasitics and irreversibilities are kept to a minimum while maintaining reasonable constraints on heat exchanger size, the technically feasible rating for a residential air conditioner is expected to be on the order of 30 EER. However, such a system would not be commercially practical since it would require an expander and would possess heat exchangers that would make the system too large for residential service.

4.4.3 Commercially Practical Efficiencies

Given the conventional use of an expansion valve or orifice, condenser and evaporator size limitations, and projected improvements in compressor and heat exchanger technology, the highest efficiency level expected to be commercially practical for a 3-ton system is on the order of 16 EER by 2007. According to the *ARI Unitary Directory (Feb - Jul 1998)*, the highest EER available in that capacity currently is 14.65 EER. The highest EER available in any size range is 15.15 in a 47,000 BTU (nearly 4 ton) system.

Although EER is a straightforward measure of equipment efficiency at a particular set of test conditions, the federal efficiency standard is based on the Seasonal Energy Efficiency Rating, or SEER test. The SEER test attempts to quantify the energy consumed by an air conditioning system over an entire cooling season in a typical U.S. home as a function of the cooling load. Although the SEER test procedure differs with the type of system being rated, it favors equipment that performs most efficiently at an 82°F outdoor ambient temperature—much lower than the 95°F EER test point. The SEER test also considers cyclic losses caused by equipment startup and shutdown.

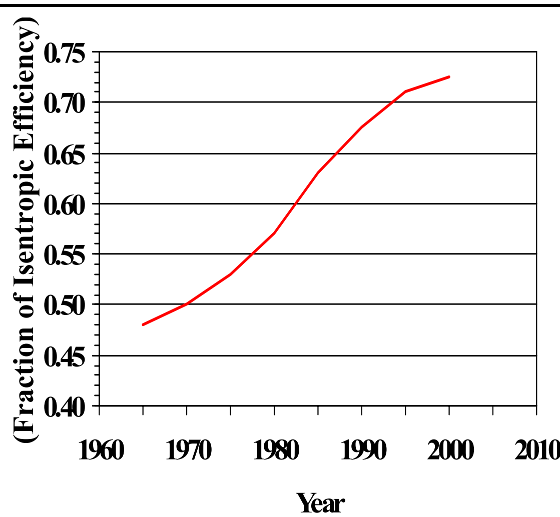
There is no direct relationship between EER and SEER across product types. However, there are strong correlations in systems with single capacity, single speed compressors and in systems that are totally modulating (see Figure 4.6). Assuming a commercially feasible limit of 16 EER, the relationship would suggest a potential commercially feasible SEER rating of 20 SEER. However, given that we are not aware of any equipment or prototype that has ever exceeded 18 SEER, we would identify 18 SEER as the Max Tech level to be used in the rulemaking.

It is important to note that only about half of all air conditioner condensers sold are paired with fancoils. The other half are paired with cased coils and therefore are not capable of using evaporator blower energy savings or fan modulation to raise their SEER ratings. For these cased coil systems, the Max Tech selection would be substantially less than the 18 SEER identified for fancoil systems. A closer estimate would be approximately 14.5 SEER. However, since fancoil and cased coil systems are not considered to be separate product classes, the Max Tech used must be the highest efficiency attainable by any member of the class. Still, if manufacturers are to be able to sell cased coil equipment, the standard level must remain below 14.5 SEER.

4.4.4 Prospects for Near-Term Efficiency Gains

The commercially practical efficiencies outlined above exceed the best efficiency of today's equipment by over 1 EER (6 percent) and 2 SEER (10 percent). That improvement requires advances in several system components.

The compressor would be the first place to look for efficiency gains, but as Figure 4.3 illustrates, compressor efficiency has been topping out after rapidly increasing over the past two decades. Compressor manufacturers expect no more than a 3 percent increase in compressor efficiency by 2007.



Courtesy of Copeland Corporation (1998)

Figure 4.3 Historical Compressor EER Improvements

According to some manufacturers, fan motors and improved air flow present the greatest potential for efficiency gains. Conventional permanent split capacitor (PSC) motors operate at typically 60 percent efficiency. Electrically commutated motors (ECMs) can boost that to more than 85 percent. However, the highest efficiency systems already incorporate ECMs, and there is no prospect for further efficiency improvement in ECMs the near future. There may be opportunities to improve internal air flow and slightly reduce fan power consumption in both the indoor and outdoor units. This would rely on improvements in fan design and cabinet configuration and contouring.

Friction losses related to refrigerant flow restrictions are difficult to reduce without increasing the flow diameters within the system. However, larger tube sizes reduce heat transfer and impede oil return. Equipment must meet these types of size and operational constraints in order to be considered commercially practical. Therefore, no near-term reductions in refrigerant flow resistance are expected.

Heat exchanger improvements can improve system efficiency by lowering condensing temperatures, increasing evaporator temperatures, or lowering fan power consumption. Current round tube, plate fin (RTPF) technology is mature, however, and no significant advances are expected. Other heat exchanger designs, such as microchannel, can be more effective, and could raise the EER achievable in residential systems slightly higher than the 16 EER level we identified as the technological limit.

4.4.5 Not-in-kind Cooling Technologies

Although the vapor compression cycle dominates air conditioning technology, other not-in-kind cooling effects exist that are not subject to many factors that constrain the efficiency of conventional equipment. Four not-in-kind technologies are *absorption, evaporative, dessicant* and *thermoelectric* cooling. None of these is compatible with the definition of central air conditioners in NAECA[e], so are not considered further.

4.5 EMERGING TECHNOLOGIES

The reverse engineering cost estimation methodology lends itself to the analysis of products that are currently available. However, assessing the effects of emerging technologies that have not found their way into the market requires additional analysis based on those results. Emerging technologies can be incorporated into a reverse engineering analysis if their effects on the cost and efficiency of conventional systems are known.

For example, assume that a manufacturer is developing a new high-efficiency compressor, and that modeling data suggest that replacing a conventional compressor with the advanced compressor could boost system efficiency from 10 SEER to 11 SEER. Knowing the price of the new compressor, the cost of the 11 SEER system can be determined by adding the cost of the new compressor to the cost of the 10 SEER components. If the difference in price between the conventional and new compressors is less than the difference in manufacturing cost between the balance of the two systems, the new compressor will lower the cost-efficiency curve at 11 SEER.

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[e] The term "central air conditioner" means a product, other than a packaged terminal air conditioner, which: (A) is powered by single phase electric current; (B) is air-cooled; (C) is rated below 65,000 Btu per hour; (D) is not contained within the same cabinet as a furnace the rated capacity of which is above 225,000 Btu per hour; and (E) is a heat pump or a cooling only unit.

This technique can assess the impacts of more than one emerging technology at a time. Suppose test data show that substituting an advanced heat exchanger into a conventional system can have the same effect, boosting efficiency from 10 SEER to 11 SEER. Since the compressor and the heat exchanger are independent, their cost impact on the system can be estimated as the product of both individual impacts on the system. Components that are not perfectly independent would have a lesser combined effect.

Although convenient and transparent, this technique is only an estimate of the potential impact of emerging technologies on the conventional cost-efficiency relationship. When certainty is essential, the technique cannot substitute for testing or modeling. The emerging technology analysis can suggest the likely effect on the reverse engineering cost-efficiency curve, but should not be considered definitive.

4.5.1 Technological Advances to be Considered

Chapter 3 introduced the emerging technologies that pass the NAECA screening criteria:

- Variable speed motor control (DC controllers and AC inverters)
- Advanced compressors (Bristol TS™, Copeland Modulating Scroll™)
- Microchannel heat exchangers

This section further explains these technologies and assesses their potential impacts on the production costs of the conventional systems estimated using reverse engineering.

4.5.1.1 Variable Speed Motor Controls

Because of practical limitations on equipment efficiency as measured by EER, variable speed (VS) systems dominate the market over 14 SEER, and it is rare to find a system over 13 SEER that does not incorporate a variable speed indoor blower. In addition to the SEER benefits provided by VS systems, they are more flexible than single-speed systems and offer consumers added comfort and lower energy consumption.

VS systems currently use either alternating current (AC) inverters or direct current (DC) controllers depending on the motor type. For example, a type of permanent magnet DC motor, the electrically commutated motor, (ECM) is now the typical choice as an indoor fan motor in high SEER systems. The SEER benefit is a combination of higher motor efficiency (80 percent versus 60 percent) and variable speed capability.

With compressor and fan motor efficiencies already nearing their practical limits, manufacturers will continue to turn to VS systems for cost effective SEER boosts. Continued advances in power supply and digital control technologies will make VS systems more reliable and less costly. These trends will tend to drive the use of variable speed systems in lower SEER levels and will lower the cost of systems over 14 SEER. Manufacturers can choose to give up some of the SEER gains by making high efficiency systems smaller and more marketable.

With all their potential benefits, VS systems have some significant drawbacks that could prevent manufacturers from favoring them in their mass market products. First, many residential service technicians have not been exposed to control systems as complex as those found in VS equipment. Manufacturers are likely to introduce such systems slowly to allow contractors ample time to hire and train qualified technicians so that VS systems do not gain a reputation for poor quality and high repair costs. Second, power electronics generate electrical noise. If not properly filtered, the noise can affect sensitive electronics elsewhere in the power grid and can generate radio interference. Stricter filtering requirements would add to the cost of VS equipment and may make them less cost effective.

While VS fan motors are certainly viable, the largest SEER impact comes from incorporating VS technology into compressors. The current SEER test does not offer VS systems much of a benefit over two-capacity equipment, so existing VS compressor controls are generally not cost effective. However, developments in switched reluctance motors (SRMs) and ECMs for hermetic compressors could ultimately offer a true VS compressor at only a slight premium over a single-speed compressor equipment.

4.5.1.2 Advanced Compressors

Compressor manufacturers are pursuing advanced designs that can raise EER and SEER ratings. Most of these efforts are still confidential, but manufacturers have announced two products that show particular potential. Both the Copeland Modulated Scroll™ and the Bristol Twin-Single, or TS™, reciprocating compressor will offer original equipment manufacturers (OEMs) the ability to produce a simple two-capacity system that our analysis suggests will be cost effective in the range of existing modulating systems.

The TS™ deactivates one of its two pistons when running in reverse. A TS™ system requires additional compressor motor controls and a two-speed indoor blower motor inverter. York began offering TS™ systems in an upgraded version of its Stellar product line in the summer of 1999.

The other advances in compressor technology come from Copeland who introduced its Modulated Scroll™ technology in early 2000. The Modulated Scroll™ also functions as a two-capacity compressor, and OEMs would use it for the same reasons. Rather than reversing direction, the Modulating Scroll™ bypasses refrigerant internally to achieve a lower capacity at a single speed. The compressor offers many of the same advantages as Bristol's TS™ and could provide an alternative in larger, quieter systems where the scrolls have held the advantage over reciprocating compressors.

Modulating compressors perform best at low capacity. At high capacity, they are likely to be slightly less efficient than their single capacity counterparts. To fully utilize the potential of full modulation in a complete system, we assume that low cost two speed inverters are used to drive indoor and outdoor fans when a modulating compressor is used.

4.5.1.3 Microchannel Heat Exchangers

Several companies produce a heat exchanger for the automobile industry known as microchannel. Unlike a conventional round tube plate fin (RTPF) heat exchanger, the microchannel has a rectangular cross-section containing several small channels through which refrigerant passes. Fins pass between the tubes and are brazed to the tubes. All components are aluminum. The resulting microchannel coil transfers more heat per unit of face area than does an RTPF coil of comparable capacity. It does so with a lower airside pressure drop, yielding reduced fan power consumption. These benefits can improve system EER and SEER ratings in residential air conditioners when compared to a condenser coil of the same face area. Because the microchannel fin arrangement prevents natural condensate drainage, heat pump and evaporator coil applications are not forthcoming.

Although the microchannel heat exchanger costs more to produce than a conventional RTPF coil, the microchannel heat exchanger offers particular opportunities to reduce the size and weight of the heat exchanger. Those advantages led to the rapid and almost total transition of the automobile air conditioner market to microchannel technology. Microchannel heat exchangers also offer significant reductions in refrigerant charge, which suggests that they reduce compressor failures due to refrigerant slugging. A reduction in refrigerant charge can also be attractive as the price of HCFC-22 rises and more expensive alternative refrigerants take its place.

Even after several years of dominance in the automobile market, the microchannel heat exchanger has not penetrated the building air conditioning markets where size and weight constraints are not as important. The cost advantages of reducing the size and weight of the condenser or the capacity of the system have not outweighed the added costs and risk associated with the microchannel technology in building applications. Several limitations and uncertainties are particularly hindering the adoption of microchannel heat exchangers. First, microchannel construction makes condensate removal much more challenging. That poses a serious barrier to the adoption of the technology in evaporators and in heat pump condensers. Some manufacturers may decide not to adopt the new technology if they cannot offer it in all of their products. Second, there are concerns whether residential heat exchangers are proven to perform well under wide variations in ambient temperatures given that they are considerably larger than automobile heat exchangers and are configured differently. Third, compressor lubrication is entrained in the refrigerant, and residential microchannel heat exchangers must display a proven ability to consistently return lubricant to the compressor to avoid costly damage. Fourthly, manufacturers are concerned that contractors will not be able to repair coil leaks effectively because of the difficulty of successfully brazing aluminum in the field.

With the possible exception of condensate removal, none of these barriers seems insurmountable, but without a clear cost advantage over conventional coils manufacturers have had little incentive to make determined efforts to address them. Recent activity indicates the attitude may be changing, however. Several major OEMs have performed limited testing of microchannel heat exchangers in residential equipment. One small company, Peregrine Industries, offers a residential condenser line based on microchannel technology for sale in coastal markets[8]. Thermal Components, a supplier of heat exchangers, including microchannel, expects several air conditioner OEMs to produce air conditioners utilizing microchannel condensers beginning later in 2000 and extending into 2001.[9] OEMs may be finding that microchannel heat exchangers offer advantages in reductions of SKUs, shipping costs, warrantee costs, and condenser size that outweigh any production cost disadvantage they may have. The transition to microchannel heat exchangers is therefore a somewhat subjective business decision, and the future of microchannel technology in residential air conditioner applications is difficult to predict with certainty.

There is unresolved intellectual property litigation surrounding microchannel technology. It is possible that a few companies or even a single company could be granted exclusive rights to sell and license microchannel heat exchangers in the United States.

4.5.2 Potential Cost Impacts of Emerging Technologies

Various OEMs and suppliers provided us with guidance of how to estimate the impacts of each emerging technology on a system. We compiled that information and applied our own judgement to develop guidelines for estimating the cost of a system utilizing a single emerging technology at each efficiency level using the cost data generated by the reverse engineering analysis. Those guidelines are presented in Table 4.16. Since we intend to present only a roughly accurate projection of the potential of emerging technologies to reduce system cost, we have not evaluated prototype designs to verify the accuracy of our estimates, nor have we asked OEMs or suppliers to verify our assumptions.

Table 4.16 Key Assumptions used to Derive Emerging Technology System Cost Estimates

Equipment Efficiency (SEER)	VS Compressor Motors	Advanced Modulating Compressors	Microchannel Heat Exchangers	Next Generation VS Fan Motors
10	-not applied-	-not applied-	80% increase in outdoor coil costs, no coil labor, 20% decrease in cabinet size and freight cost, 58% decrease in refrigerant charge	-not applied-
11	-not applied-	-not applied-	Similar to 10 SEER modifications	-not applied-
12	-not applied-	10 SEER conventional system with: compressor cost +10%; outdoor unit electronics + $30; indoor unit electronics + $25	Similar to 10 SEER modifications. Used 10 SEER compressor price and 10 SEER condenser chassis.	-not applied-
13	-not applied-	11 SEER conventional system with same changes as 12 SEER	Similar to 10 SEER modifications. Used 12 SEER compressor price and 11 SEER condenser chassis.	-not applied-
14	-not applied-	12 SEER conventional system with electrical and compressor costs of the modified 13 SEER system	Similar to 10 SEER modifications with only 60% increase in coil cost. Used 12 SEER compressor price and condenser chassis and 12 SEER indoor electrical materials	14 SEER conventional system with $125 indoor electronics
15	13 SEER compressor $130 outdoor unit electronics	13 SEER conventional system with electrical and compressor costs of the modified 13 SEER system	Similar to 14 SEER modifications.	15 SEER conventional system with $125 indoor unit electronics

In cases where the emerging technology would obviously raise the cost of the system, we did not develop a guideline or estimate the system cost, and "not applied" appears in Table 4.16.

Table 4.17 summarizes our conclusions regarding potential impact of each emerging technology on a 3-ton split air conditioning system with a fancoil. The reverse engineering results captured in the *CAC Cost v3.1* spreadsheet (Appendix B) were used to estimate the cost impacts of emerging technologies by substituting components at each efficiency level in accordance with the guidelines in Table 4.16.

We assume that OEMs will adopt a new technology only if it promises to lower the cost of the system relative to conventional technologies. Therefore, if a technology tends to increase the cost of a system, the amount of increase is not reported.

Table 4.17 Potential Impact of Emerging Technologies on the Production Cost of 3-ton Split Air Conditioners with Fancoils by 2007

Efficiency Level	VS Compressor Motors	Advanced Modulating Compressors	Microchannel Heat Exchangers	Next generation VS Fan Motors
10	+	+	+	+
11	+	+	-5%	+
12	+	+	-2%	+
13	+	+	-1%	0%
14	+	-22%	-17%	-7%
15	+	-23%	-21%	-5%
16	-6%	-27%	--	-5%
17	-6%	--	--	--

+ Tends to raise production costs
– Not enough information to assess cost impacts

No emerging technology identified promises a clear benefit in equipment rated lower than 14 SEER. The incremental costs of applying the technology exceed the savings achieved in the balance of the system. At 14 SEER and 15 SEER, however, advanced modulating compressors and microchannel heat exchangers both have the potential to eliminate the need for costly variable speed fan motor controls as well as reducing cabinet size and refrigerant charge.

Table 4.18 provides an assessment of the likelihood that the product will be the dominant design choice in baseline equipment at the time a new standard becomes effective (2006) under a standard level that is most favorable to it. This means that a product will be practical and functional at price point acceptable for mass market products and will be the most attractive technology employed. This assessment reflects the level of resistence to the broad adoption of a new technology given the other viable alternatives.

Table 4.18 Estimated Likelihood of Commercial Dominance in Baseline Equipment by 2006 Under Various Standard Levels

	10 SEER	11 SEER	12 SEER	13 SEER
VS Compressor motors	0%	0%	0%	10%
Advanced modulating compressors	0%	0%	10%	30%
Microchannel heat exchangers	20%	20%	30%	40%
VS Fan Motors	0%	0%	10%	40%

The microchannel heat exchanger, since it offers cabinet size reductions without the added complexity of controls and without requiring an indoor blower, has the highest potential of being used in baseline equipment. However, along with other potential drawbacks, not being applicable to indoor coil and heat pump applications limits its potential use to cooling-only condensers.

As Table 4.19 shows, for premium equipment with efficiency ratings higher than the baseline, manufacturers will still likely choose a modulating technology option, although it is unclear whether they would decide to do so rather than offer microchannel heat exchangers.

Table 4.19 Estimated Likelihood of Commercial Dominance in Premium Equipment by 2006 Under Various Standard Levels

	10 SEER	11 SEER	12 SEER	13 SEER
VS Compressor motors	10%	10%	10%	10%
Advanced modulating compressors	20%	30%	60%	70%
Microchannel heat exchangers	20%	20%	30%	60%
VS Fan Motors	20%	20%	50%	90%

Finally, we considered the potential impact on system costs that could be achieved by combining multiple technologies in a single system. Variable speed compressor motors and next generation variable speed fan motors are not beneficial in a baseline system since a system utilizing an advanced modulating compressor or microchannel heat exchanger would require neither of these and would have a cost advantage. Therefore, the combination of the advanced modulating compressor and the microchannel heat exchanger is likely to be the only combination of emerging technologies that would be used in practice. Such a system would be a dual-capacity microchannel heat exchanger system designed primarily for low-capacity operation, incorporating a modulating compressor and its associated controls. The low-capacity design reduces coil and cabinet sizes and costs, but does not reduce the size of the compressor since compressor capacity is established at the high capacity.

Since both technologies remove the need for variable speed controls or a second or dual compressor, the combination of the two technologies produces a more costly system than does using either separately. Therefore, we would not expect hybrid systems to be used except in cases where space constraints are particularly severe.

4.5.3 Potential of Emerging Technologies to Benefit Niche Products

Emerging technologies can have an even more significant impact on many of the niche products identified (Section 4.6.2.2). Cabinet size is a major constraint to improving niche product efficiency, and all of the emerging technologies can improve either EER or SEER ratings without increasing size. Niche products that face condenser constraints (through the wall packaged equipment and split condensers) can benefit the most. Fancoil units benefit the least since microchannel heat exchangers are not applicable because of their condensate removal limitations.

4.5.4 Issues Associated with Proprietary Technologies

Where a company holds exclusive rights to produce and sell an emerging technology, a new standard that favors that technology can potentially reduce competition. At this point, however, the Department believes that enough viable competing technologies exist at each efficiency level to encourage vigorous competition at any potential standard level. The Manufacturing Impact Analysis (Chapter 8) describes further expected impacts on competition.

4.6 PRODUCT CLASSIFICATIONS

NAECA segmented central air conditioners into four classes: split cooling-only, split heat pump, packaged cooling-only, and packaged heat pump. The Department assessed whether these class designations are justified and whether new classes are needed.

4.6.1 The Case for Eliminating or Combining Existing Classes

The four existing product classes are defined based on 1) whether equipment provides cooling only or also provides electric heating, and 2) whether a system is split or packaged. This section examines whether those four classes are justified from a technical standpoint.

4.6.1.1 Heat Pump versus Cooling-only

In addition to the features offered by cooling-only air conditioners, heat pumps offer electric heating. This unique feature and the different energy use that results continue to support separate classifications for heat pumps. No manufacturer has expressed a strong desire to eliminate the separate classifications for heat pumps.

In Section 4.8.1 the relationship between seasonal heating efficiency (HSPF) and seasonal cooling efficiency (SEER) is examined to determine whether the separate HSPF standard is warranted.

4.6.1.2 Split versus Packaged

The special installation capabilities for packaged systems also offer utility that differs from that of split systems. This supports the separate classes for packaged systems. The Department examined whether the different efficiency standards for packaged systems are justified from a technical standpoint.

Packaged systems currently face less stringent SEER and HSPF standards than do split systems. The intent is to compensate packaged equipment for efficiency losses due to heat transfer between the evaporator and condenser compartments. There are two reasons why packaged equipment may not require a lower efficiency standard.

First, split systems incur refrigerant line losses that packaged systems do not incur. Some manufacturers have expressed that line losses and cabinet losses are similar in magnitude, and therefore, packaged systems do not deserve an efficiency advantage.

Second, no physical constraint prevents a typical packaged systems from attaining the same minimum efficiency as split systems.[f] Boosting the efficiency of packaged systems by 0.3 SEER to match that of split systems is trivial from a design standpoint. Based on the reverse engineering analysis, the costs of raising packaged system efficiency by 0.3 SEER is expected to be roughly 3 percent. This added cost is not trivial, but we would not expect it to alter the distribution of sales in the marketplace. In fact, as Table 4.20 shows, most manufacturers do not take advantage of the lower standard currently. They prefer instead to incur a bit more cost to align their marketing approach with that of their split systems.

[f] There are niche packaged products that do face special size constraints which are considered separately.

Table 4.20 Available Packaged Systems Models Rated at and below 10 SEER

SEER	PAC	PHP
9.70-9.99	15	4
10.0	96	89

Source: *ARI Unitary Directory*, February-July 1998

At higher efficiency levels, packaged systems possess an advantage over split systems. Since they are usually roof-mounted, they typically face less stringent footprint and height constraints. Although weight constraints can be important, packaged systems can attain higher EER ratings than split systems by using larger evaporator and condenser coils.

No manufacturer has expressed a strong desire either to continue or to eliminate the disparity between efficiency standards between packaged and split systems.

Packaged systems continue to possess unique utility. However, there is not strong technical argument why the two classes must continue to have different efficiency standards.

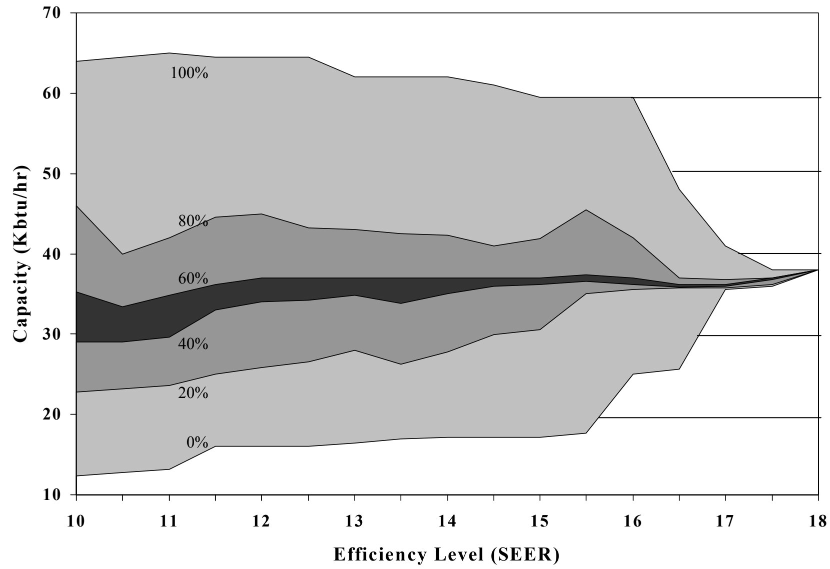
4.6.2 The Case for Creating Additional Classes

Some manufacturers have expressed a desire for the Department to create classes other than the four that are currently established. This section assesses those proposals.

4.6.2.1 Classes for Different Cooling and Heating Capacities

During the manufacturer interviews, some manufacturers remarked that they have more difficulty attaining higher efficiencies in low and high capacity systems (below 30,000 BTU/h and above 48,000 BTU/h) than in mid-capacity systems. This situation could justify the creation of new product classes based on product capacity and allow the Department to impose a less aggressive standard on small and large capacity equipment.

According to manufacturers, low capacity equipment has difficulty meeting higher standards because 1) efficient compressors are more costly to produce in small capacities, and 2) cyclic effects are more severe. High capacity, high efficiency equipment faces cabinet constraints. Figure 4.4 seems to support these contentions. Each band in the figure represents 20 percent of the split air conditioner models available at each efficiency level. Low and high capacity models become increasingly scarce at efficiencies higher than 15 SEER.



Source: *ARI Unitary Directory*, February-July 1998

Figure 4.4 Distribution of Split Air Conditioner Models by Capacity and Efficiency

Weak demand is another reason system manufacturers do not offer low capacity systems in higher efficiencies. This is a combination of two market effects. First, as Table 4.21 illustrates, fewer consumers purchase low capacity equipment in general. Second, since low capacity systems use less energy, price is more important to consumers relative to efficiency. More stringent efficiency standards would guarantee strong demand for high efficiency, low capacity equipment. This would likely stimulate the development of efficient components in smaller sizes and encourage system manufacturers to incorporate them. Higher standards would also encourage manufacturers to boost SEER by reducing cyclic losses and expanding their offering of modulating systems.

Table 4.21 Shipments of Residential Unitary Condensers by Capacity (1996)

Capacity (BTU/hr)	Nominal Capacity (tons)	Quantity Shipped	Percent Shipped in Class
Split Air Conditioners			
Under 22,000	1-1/2	304,748	8%
22,000 to 26,999	2	921,717	23%
27,000 to 32,999	2-1/2	881,477	22%
33,000 to 38,999	3	836,423	21%
39,000 to 43,999	3-1/2	396,722	10%
44,000 to 53,999	4	389,728	10%
54,000 to 64,999	5	323,793	8%
Split Heat Pumps			
Under 27,000	1-1/2 to 2	314,239	32%
27,000 to 41,999	2-1/2 to 3-1/2	467,573	47%
42,000 to 64,999	3-1/2 to 5	209,339	21%
Packaged Air Conditioners			
Under 27,000	1-1/2 to 2	19,983	11%
27,000 to 32,999	2-1/2	35,546	19%
33,000 to 53,999	3 to 4-1/2	96,673	52%
54,000 to 64,999	5	35,497	19%
Packaged Heat Pumps			
Under 27,000	1-1/2 to 2	30,204	16%
27,000 to 41,999	2 to 3-1/2	95,624	50%
42,000 to 64,999	3-1/2 to 5	63,939	34%

Source: U.S. Bureau of the Census *MA-35M-96*

High capacity systems do face cabinet size constraints in single capacity systems. Modulating systems do not face the same constraints, so weak demand is probably responsible for the lack of high capacity, high efficiency products. Emerging technologies can also play a role in easing cabinet constraints (Section 4.6.2.4.3).

Since the absence of products at all efficiency levels results from a lack of demand for those products and not from any strict physical limitation, the Department finds no compelling technical justification for defining new product classes based on capacity.

4.6.2.2 Classes for Niche Products

Several manufacturers have asked the Department to establish new classes to protect the viability of certain niche products under higher efficiency standards. Table 4.22 provides some key information on these products.

Table 4.22 Characteristics of Niche Products

Niche Product	Key Manufacturers	Key Physical Constraints	Typical Application
Ductless splits	Mitsubishi Electronics Carrier Sanyo Fisher Enviromaster International	Small cabinet size Refrigerant line loss	Residential retrofit and small commercial
High-velocity, small duct	Unico Mestek	High static pressure Low evaporator temperature Small cabinet size	Residential retrofit New high-end homes
Vertical packaged, wall mounted	Bard	Small cabinet size Poor airflow	Factory-built commercial buildings and enclosures
Through-the-wall condensing unit	First Company National Comfort Products Enviromaster International	Small cabinet size Poor air flow	Multi-family retrofit
Through-the-wall packaged unit	First Company Skymark Armstrong (Lennox)	Small cabinet size Poor air flow	New multi-family

All these products serve niche markets and probably account for less than 3 percent of the residential unitary market. As such, the efficiency standard established for these products will have little effect on national energy savings and consumer life cycle cost calculations. However, each is a unique product with some unique utility. The question is whether the constraints these products face justify separate classification and different efficiency standards from other products.

4.6.2.2.1 Ductless Splits

Ductless split systems, or mini-splits as they are commonly known, dominate the international market but hold only about 1 percent of the domestic market. They consist of a single outdoor unit and an indoor fancoil unit discharging directly into the conditioned space. (Ductless systems with multiple fancoil units are often called multi-splits.) Mini-splits are attractive in many applications because tubing and electrical service can often be installed for less cost and in less space than can the equivalent ducting. This makes them particularly attractive for the retrofit market. They also offer the possibility of true individual temperature control. Since consumers may consider the interior units to be more intrusive than a ducted system, manufacturers strive to make them as compact as possible. This cabinet size constraint combined with efficiency losses due to heat transfer between refrigerant lines puts pressure on equipment efficiency.

4.6.2.2.2 High Velocity, Small Duct

High velocity, small duct fancoil units target primarily the retrofit market. According to the manufacturers, the small, easy to install ducts, non-intrusive discharges, and silent operation make these units attractive for many retrofit situations where consumers' space is a premium, and where installing a conventional split system is cost prohibitive. Architectural and aesthetic advantages also make this a viable product for high-end custom homes.

High velocity systems are designed to discharge conditioned air rapidly through round ducts that can fit inside stud walls. Blowers must, therefore, overcome high static pressures. To mitigate the burden on the blowers, designers reduce the required air volume by cooling it more than a conventional system. This increases the cost through added tube rows and larger capacity, but offers the associated benefit of enhanced humidity removal.

The inefficient fancoil unit in high velocity systems requires them to pair with high efficiency condensing units (typically 13 - 14 SEER) to attain the 10 SEER NAECA minimum. Mestek's SpacePak product offers equipment rated at 12.0 SEER.

Contractors typically install fancoil units outside the conditioned space, penalizing efficiency in the field. However, the manufacturers of high velocity systems claim that the ducts are tight and durable, and that superior dehumidification will cause occupants to raise their thermostat settings. Both would lower energy consumption compared to conventional systems of equal SEER ratings.

4.6.2.2.3 Vertical Packaged, Wall Mounted

Manufacturers design these products for installation in mobile or modular structures, which are almost exclusively commercial applications. However, manufacturers may offer them with single-phase motors, placing them under NAECA. The difficult air flow configuration (each of the condenser and evaporator compartments takes air in and exhausts it through the same face) combined with the attempt to minimize size constrains the ability of these units to attain higher SEERs.

4.6.2.2.4 Through-the-wall Condenser

Through-the-wall condensers were popular in new multistory residential construction in the 1960s and 1970s. Major manufacturers have since abandoned the replacement market, providing an opportunity for lower volume manufacturers. Most equipment is in the 1-1/2 to 2-1/2 ton capacity range.

New through-the-wall condensers must fit within the same wall opening as the original units, even though original units may be half as efficient as the new ones. Residents or building owners are particularly sensitive to any increase in price or to the cost of enlarging the wall opening to accommodate a larger condenser. Since repair is the only other cost effective alternative to replacement, a new standard that increases cabinet size or results in a significant price increase could be counterproductive, preventing the turnover of old, inefficient equipment.

4.6.2.2.4 Through-the-wall Packaged

Through-the-wall packaged equipment is similar to packaged terminal air conditioners (PTACs), but are typically installed in a closet and ducted to the interior space. Like through-the-wall condensing units, they serve primarily multi-family high rise applications. However, unlike today's through-the-wall condensing units, through-the-wall packaged units are targeted to new construction without prior wall opening constraints.

4.6.2.3 Description of Niche Product Constraints

4.6.2.3.1 Small Cabinet Size

Cabinet size constrains efficiency primarily by restricting coil face area and coil configuration. As face area decreases, the velocity of the moving air increases. This slightly improves the heat transfer between the air and the coil, but it also increases the pressure drop across the coil and increases the power consumption of the blower or fan. As face area shrinks, the increased fan power negates any benefits from improved heat transfer and lowers the efficiency of the system. The face area limitation is particularly important in the condenser where the similarity between ambient air temperature and refrigerant temperature requires higher air volumes to transfer the same amount of heat. In the evaporator, the temptation to increase coil face area to reduce blower power consumption and increase cycle efficiency is somewhat counteracted by the need to provide adequate dehumidification.

A cramped cabinet may also make it difficult, or impossible, to install optimal components or technical upgrades, like controls, that could improve system efficiency.

4.6.2.3.2 Poor Airflow Configuration

The orientation of air intake and discharge and the internal path of the airflow can affect system efficiency. Most split system outdoor units take in air horizontally around their entire perimeter and discharge it vertically upward. Restricting the outdoor unit to take in air through only one face, or to take in and exhaust air through the same face can reduce efficiency by increasing fan power consumption. Some short-circuiting of exhaust air into the intake may also occur. Indoor units typically take in air horizontally near the bottom of the unit and discharge it vertically at the top.

Other configurations may boost or harm efficiency. In either the indoor and outdoor unit, sharp changes in airflow direction can increase blower power consumption and may also result in uneven airflow over the coil, resulting in only partial coil use.

Packaged units may suffer from the same airflow related problems, with the additional possibility of heat transfer or air leakage between the evaporator and condenser compartments.

4.6.2.3.3 High Static Pressure

Higher indoor static pressure causes the blower to work harder at a given capacity and airflow. The Department's test procedure prescribes minimum static pressures, and products that exceed them may be penalized through higher blower power consumption than is assumed in the test procedure. This constraint is particularly relevant to manufacturers of high-velocity, small duct systems, but also affects other niche products as well.

4.6.2.3.4 Low Evaporator Discharge Temperature

Producing a lower than normal air temperature from the evaporator requires either more tube rows or a slower face velocity. Under cabinet size constraints, these improvements may not be possible. Furthermore, the additional heat transfer increases the required capacity of the condensing unit.

4.6.2.4 Remedies for Niche Product Constraints

Most niche manufacturers, although they serve specialized markets, still attempt to keep costs at a minimum. Since many niche products serve manufactured and multifamily housing markets, specifiers and consumers may be especially price-conscious. Furthermore, because of the low sales volumes, many niche manufacturers have no real market incentive to supply higher efficiency products. Many manufacturers do not pursue advanced designs for those reasons. Standards that apply evenly to their competitors would allow them to introduce more expensive, but more efficient, design options without losing market share or reducing profit margins. Several of these design options can ease the efficiency constraints that niche products face.

4.6.2.4.1 More Efficient Components

Many niche products use motors and compressors with only moderate efficiency or fixed orifice expansion devices. Those products can upgrade to higher efficiency or variable speed components without exceeding performance or size constraints, but these modifications would raise production costs. Depending on the cross-price elasticity with competing products, any increase in price could result in a substantial loss of market share.

4.6.2.4.2 Larger Cabinet Size

Through-the-wall and wall mounted packaged equipment and ductless splits do not face a rigid size constraint. A manufacturer may lose sales when it increases cabinet sizes to attain higher efficiencies, but no clear thresholds exist above which its products cease to be commercially viable. Without thresholds, the Manufacturer Impact Analysis is the appropriate analysis for determining whether a standard level threatens the viability of the product.

4.6.2.4.3 Use of Emerging Technologies

Emerging technologies, especially advanced modulating compressors and microchannel heat exchangers, are attractive options for niche products whose primary constraint is condenser size. This would include through-the-wall split and packaged units. It would not included high-velocity systems or ductless split systems since those systems are constrained by the size of the evaporator, which is not currently being considered as a viable application for microchannel technology because of condensate removal concerns. Furthermore, heat pump condensers, since they also require removal of condensate in the heating mode, are not expected to benefit from microchannel technology.

4.6.2.4.4 Modifications for Testing

Some niche products may benefit from modifications that allow them to operate under conditions that differ from the test conditions. For example, manufacturers of high velocity systems intend their equipment to operate under higher static pressures, lower temperatures, and lower airflows than those the test procedures prescribe. They can explore whether installing mulitap blowers or other variable speed or adjustable components could raise their SEER ratings by allowing them to test under a set of conditions more closely representative of conventional equipment while still allowing proper installation in the field.

4.6.2.4.5 Redefinition

Vertical packaged, wall mounted equipment currently falls under the definition of residential products (single phase, less than 65,000 BTU/h), but is intended for commercial application. The Air Conditioning and Refrigeration Institute has defined the product as commercial equipment. The Department may decide to classify equipment intended primarily for commercial application as covered by EPACT efficiency requirements rather than NAECA.

4.6.2.5 Justification for New Classes Based on Niche Products

One type of niche product, vertical packaged-wall mounted, is intended for commercial application with commercial operating characteristics. As such, NAECA may not be the proper governing regulation. To limit abuse, the Department could consider imposing a labeling requirement for the class to restrict those products from being installed in residential applications.

For the other niche products, Table 4.23 shows the highest viable cooling efficiency achievable for each of the candidate products utilizing both conventional and emerging technologies. Discussions with manufacturers of these products and engineering and marketing judgment are the basis for the preliminary conclusions. In this case, "viable" means technically feasible, commercially practical, and able to retain its own unique characteristics and utility. For example, consumers purchase high velocity systems for their small diameter, easy to install ducts and compact air handler. As the air handler gets larger and duct branches get more numerous, the product eventually loses its uniqueness compared to conventional systems and becomes increasingly unviable as a product with unique utility. It is also important to note that two products having the same viable efficiency level cannot necessarily achieve that level for similar costs.

Table 4.23 also lists the substitutes available for each product and the sensitivity of consumers to price increases with respect to price increases in the substitutes. High cross-price sensitivity means that a consumer will be likely to purchase the substitute if the price difference between the two products changes even slightly. This will cause consumers to shift to the substitute product, and could eventually eliminate the subject product from the market. A price differential can increase when a new efficiency standard results in a more severe price increase in the subject product than in the substitute. In cases where the substitute faces a less stringent efficiency standard (e.g. window units, repair), a new efficiency standard could reduce national energy savings by driving consumers to the less efficient substitutes.

Table 4.23 Assessment of Factors that Influence the Decision to Establish Separate Classes for Niche Products

Niche Product	Estimated Highest Viable Efficiency Level (SEER)		Substitutes (ranked in order of decreasing attractiveness for most typical applications)	Efficiency of Substitute	Cross- price sensitivity
	Conventional Technology	Emerging Technology			
Ductless split	12.0	12.0	1. Window 2. High-velocity 3. Conventional split	Lower Same Higher	Moderate
High-velocity, small duct	12.5	12.5	1. Window 2. Ductless split 3. Conventional split	Lower Same Higher	Low
Vertical packaged, wall mounted	12.0	12.5	1. Conventional packaged	Higher	Moderate
Through-the-wall condenser	11.0	13.0	1. Repair	Lower	High
Through-the-wall packaged	12.0	15.0	1. Hydronic systems 2. Conventional split	Higher Higher	High

4.6.3 Possible Loopholes Created by Product Class Definitions

Anytime two product classes exist with different efficiency standards, there is the potential for companies to attempt to exploit the lower standards. Taking steps to define the products as carefully as possible and to ensure that the new standards do not significantly alter the cost differential between the product classes can minimize the temptation to market lower efficiency products in applications traditionally served by equipment that have higher efficiency requirements. For example, there is nothing that would physically prevent a contractor from installing a through the wall condensing unit on a pad. That is not common practice today since both conventional split condensers and through-the-wall condensers must meet the same efficiency requirements and conventional split condensers are less costly. However, if through-the-wall condensers were granted a lower efficiency standard than their conventional pad-mounted counterparts, the price difference between the two systems could favor the through-the-wall equipment, causing their use in pad-mounted applications to increase. More widespread use of less efficient equipment would increase national energy consumption.

The price differential between ductless minisplits and high velocity equipment is high (about twice) that of conventional equipment at the same efficiency and capacity. Therefore, the concern about creating attractive loopholes is low for these products. Similarly, if properly defined and regulated, there is little chance that wall-mounted vertical packaged systems would find their way into conventional residential applications due to the prevalence of lower priced competing technologies.

However, the price premium for through-the-wall condensing and packaged equipment is relatively low--about 30 percent and 70 percent, respectively. For three-ton equipment, that equates to a $200 and $430 difference in manufacturer price, respectively, for the two systems compared to their conventional counterparts. To maintain those price differences, standards for through-the-wall systems would have to stay within one SEER point of the standards set for pad or roof mounted systems in order to reduce the likelihood that the market will exploit the difference and increase the demand for through-the-wall equipment in pad or roof mounted applications.

4.7 ALTERNATIVE REFRIGERANTS

Effective January 1, 2010, the Environmental Protection Agency will prohibit the sale of new equipment utilizing HCFC refrigerants, including HCFC-22 (R-22), the dominant refrigerant in unitary air conditioning systems. Researchers continue to develop and test alternative refrigerants, but a consensus is settling on two chlorine-free HFC alternatives: HFC-407C (407C) and HFC-410A (410A). Each has comparative advantages and disadvantages, particularly regarding energy efficiency.

407C is a blend of HFC-32, -125, and -134a. Its physical properties and operating characteristics make it a suitable drop-in replacement for R-22. However, 407C lowers the efficiency of unmodified R-22 systems by 5-10 percent under the SEER test conditions. Likewise, a new 407C system is likely to be more costly than an R-22 system at the same efficiency level. If 407C becomes the refrigerant of choice for new equipment, this will increase the cost of attaining a given efficiency compared to HCFC-22. Lennox has announced that they will introduce a line of light commercial products based on 407C early in 2000.

410A is an mixture of HFC-32 and -125. It operates at substantially higher pressure (50-70 percent) than does R-22 and requires a soluble polyol ester lubricant, so it is not suitable as a drop-in R-22 replacement. However, its higher operating pressure and slightly better thermodynamic properties may allow new 410A systems to achieve the same efficiencies as R-22 systems at a slightly lower cost. The higher operating pressure in 410A equipment requires either smaller tube diameters or thicker tube walls. Since 410A has a higher cooling capacity than R-22, manufacturers can preserve system capacity by reducing tube diameter (and tube cost). Furthermore, 410A can provide a slight efficiency boost at the SEER testing points. However, at the EER test point which more closely represents peak cooling conditions, 410A is about 3 percent less efficient than R-22.[10] This would exacerbate utilities' peak loading concerns. Furthermore, manufacturers will bear a significant capital conversion cost to allow plants to handle the smaller tube diameters and strict anti-contamination standards. Carrier introduced a line of products based on 410A in 1998 and most other major manufacturers have since followed suit.

Momentum is building behind 410A as the refrigerant of choice in new equipment, but it is too early to predict with absolute certainty which refrigerant will ultimately dominate by 2006. Hydrocarbons and carbon dioxide both could still dominate by 2010. However, for the 2006 rulemaking date, neither 410A nor 407C will substantially change the cost-efficiency relationship, and neither will substantially affect consumer life cycle costs. Therefore, conclusions suggested by analysis of HCFC-22-based equipment should still be valid for equipment utilizing either 410A or 407C. The issue plays a greater role in assessing the cumulative burden of new standards on manufacturers (Chapter 8).

4.8 OTHER ANALYSES IN THE ENGINEERING ANALYSIS

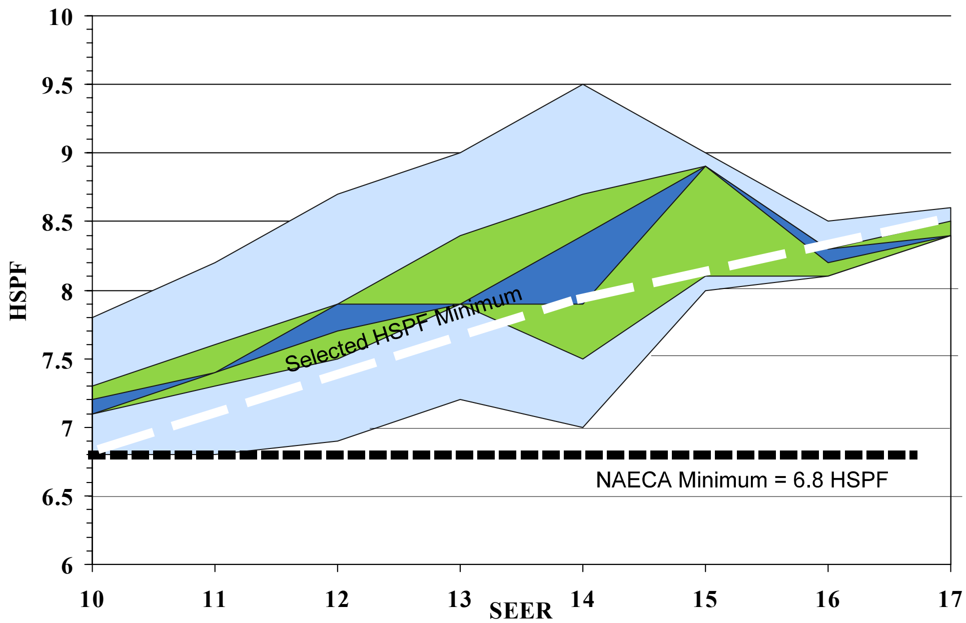
Beyond the preceding analysis, there are several other engineering issues that can play an important role in the Department's selection of trial standard levels.

4.8.1 Definition of the Relationship between SEER and HSPF in Heat Pumps

Currently, cooling efficiency standards (SEER) do not differ based on whether a system provides heating, but heat pumps do face an additional regulation on heating efficiency (HSPF). The Department investigated whether the relationship between HSPF and SEER is rigid enough to allow a SEER standard to serve as a *de facto* HSPF standard.

Since SEER and HSPF are calculated values and incorporate factors other than system physics, no rigid relationship between the two would be expected. As Figure 4.5 illustrates, a survey of available equipment supports that hypothesis. Each band in the Figure represents 20 percent of the products available at the stated efficiency level. Although HSPF generally increases with SEER, the correlation is low (0.63). However, the relationship between HSPF and SEER is surprisingly close below 13 SEER, with 60 percent of models falling within a range of 0.3 to 0.5 HSPF.

To set efficiency standards for heat pumps, the Department must determine both an HSPF level and a SEER level. This complicates the analysis since each SEER level corresponds to a broad range of HSPF ratings. To provide a rationale for selecting SEER-HSPF pairs, the Department examined histograms based on Figure 4.5 that showed the number of models possessing each HSPF at each SEER level. Table 4.24 lists the results. Median (50^{th} percentile) HSPFs are generally well above the minimum allowable HSPF, revealing that market does not apply strong downward pressure on HSPF.



Source: *ARI Unitary Directory*, Feb - July 1998

Figure 4.5 Relationship between HSPF and SEER in available 3-ton Split Heat Pumps

After examining the histograms, the Department plotted the relationship between HSPF and SEER for all 3-ton split heat pumps listed in the Spring 1998 *ARI Unitary Directory* (Figure 4.5). At 10 SEER, the difference between the minimum HSPF (6.8) and the median (7.1) is 0.3 HSPF. We then defined the equation of a line that ran generally parallel with the median HSPF at each SEER level while passing through the 10 SEER, 6.8 HSPF point:

$$SEER\ 10-14: \quad HSPF = 6.8 + 0.3 * (SEER - 10)$$
$$SEER\ >14: \quad HSPF = 8.0 + 0.2 * (SEER - 14)$$

The proposed minimum HSPF requirements are derived by inserting the minimum SEER requirements into the formula. For example, under a 12 SEER standard, all products would have to attain a minimum HSPF of 7.4.

Even though the Department does not have information on the distribution of heat pump sales by HSPF at each SEER level, it is apparent that the market currently favors products that exceed the minimum allowable HSPF level. This is due both to the natural relationship between HSPF and SEER and the preference in the market for high HSPF heat pumps in cooler climates. The Department believes that establishing an HSPF standard equal to the current median at a given

SEER level would impose an undue design constraint on manufacturers, adding to the cost and burden of designing, producing, testing, and qualifying the product without resulting in a significant increase in the average HSPF of equipment sold.

Table 4.24 summarizes the selection of HSPF standard levels. It also shows the HSPF levels that ARI considered to be the "most likely" HSPF rating at each SEER standard level. In all cases, the ARI "most likely" HSPF value exceeds the selected minimum HSPF levels, typically by 0.2 to 0.3 HSPF.

Table 4.24 Comparison of Proposed HSPF Standard Levels with Median HSPFs of Equipment Listed in the ARI Unitary Directory

Efficiency/Standard Level (SEER)	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**
Recommended minimum HSPF	6.8	7.1	7.4	7.7	8.0	8.2	8.4	8.6
Median HSPF in available products	7.1	7.4	7.9	7.9	7.9	8.9	8.2	8.4
Offset from Median (HSPF)	-0.3	-0.3	-0.5	-0.2	+0.1	-0.7	+0.2	+0.2
Increase in Minimum HSPF from Base HSPF	--	0%	67%	-33%	-133%	133%	-167%	-167%
Fraction of Available Equipment below the recommended HSPF Level	0%	<10%	10%	10%	<60%	<30%	<100%	<100%
ARI "Most Likely" HSPF	--	7.28	7.69	7.99	8.25	8.28	--	–

Table 4.25 provides a more detailed breakdown of the models available at each efficiency level in 1998 as well as the total number of models at each efficiency level.

Table 4.25 Prevalence of HSPF Ratings by SEER Level for 3-ton Split Heat Pumps with Impacts of Suggested HSPF Standards

Decile	Efficiency Level (SEER)						
	11	**12**	**13**	**14**	**15**	**16**	**17**
	Selected HSPF						
	7.1	*7.4*	*7.7*	*8.0*	*8.2*	*8.4*	*8.6*
0%	6.7	6.8	7.1	6.9	7.9	8.0	8.3
10%	7.2	7.4	7.7	7.4	8.0	8.1	8.4
20%	7.3	7.5	7.9	7.5	8.1	8.1	8.4
30%	7.4	7.6	7.9	7.6	8.4	8.1	8.4
40%	7.4	7.7	7.9	7.9	8.9	8.2	8.4
50%	7.4	7.9	7.9	7.9	8.9	8.2	8.4
60%	7.4	7.9	7.9	8.4	8.9	8.3	8.4
70%	7.5	7.9	8.1	8.4	8.9	8.3	8.4
80%	7.6	7.9	8.4	8.7	8.9	8.3	8.5
90%	7.9	8.1	8.5	8.9	8.9	8.3	8.5
100%	8.2	8.7	9.0	9.5	9.0	8.5	8.6
No. Models	1015	1127	437	257	13	36	7

Source: *ARI Unitary Directory*, February-July 1998

4.8.2 Repair versus Replace

A few parties have expressed concern that standards which are too aggressive will encourage consumers to repair old, inefficient equipment rather than replace it, and that this could actually increase national energy consumption with respect to the base case. Since most equipment sales are replacement sales, this is an important concern.

We used a simple equipment attrition model to project equipment shipments through 2030 assuming that new standards would result in the tendency to repair rather than replace equipment, thereby extending its life. Table 4.26 shows the added lifespan that would have to be at each potential standard level to result in an increase in national energy consumption over the base case (no new standard).

Table 4.26 Equipment Life Extension Resulting in Increased National Energy Consumption

Standard Level (SEER)	Necessary Years Added to Life
10.7	1
10.8	3
10.9	5
11.0	7
11.1	10
11.2	14
11.3	18

As expected, the results do not support the suggestion that higher standards would necessarily increase national energy consumption by delaying equipment replacement. For example, an 11 SEER standard would have to extend equipment life by more than seven years in order to increase energy consumption nationwide. Standards higher than 11.4 SEER will not increase energy consumption unless products survive for more than an additional 20 years. Neither scenario is likely. More likely is that a slight increase in the standard would increase national energy consumption. For instance, the change in retail price under a standard of 10.8 SEER is estimated to be about $80. According to Table 4.26, a standard level of 10.8 would increase national energy consumption if it extended equipment life beyond an additional three years.

New standards will reduce national energy consumption even if they prolong equipment life because sales into the new construction market accumulate over time. In the attrition model base case, equipment sold into homes built after 1998 consumes 15 percent of the total consumed by all residential air conditioners through 2030. That cumulative effect causes the repair-replace decision to have less of an effect on national energy consumption as standard levels rise. The Shipments analysis in Chapter 6 explores this repair-replace issue in greater detail.

4.9 ESTABLISHING A MINIMUM EER(95°F) REQUIREMENT

Many utilities and environmental advocates support the establishment of minimum efficiency standards based on EER at an outdoor temperature of 95°F, (EER(95°F)) in lieu of, or in addition to, SEER, which is based largely on an outdoor temperature of 82°F. They are concerned that an increase in SEER does not necessarily correspond to an increase in EER, and that a 95°F rating condition better represents the performance of an air conditioner on hot days when electricity demand is at its highest. They believe that residential air conditioners contribute significantly to this peak demand, particularly in warmer regions of the country.

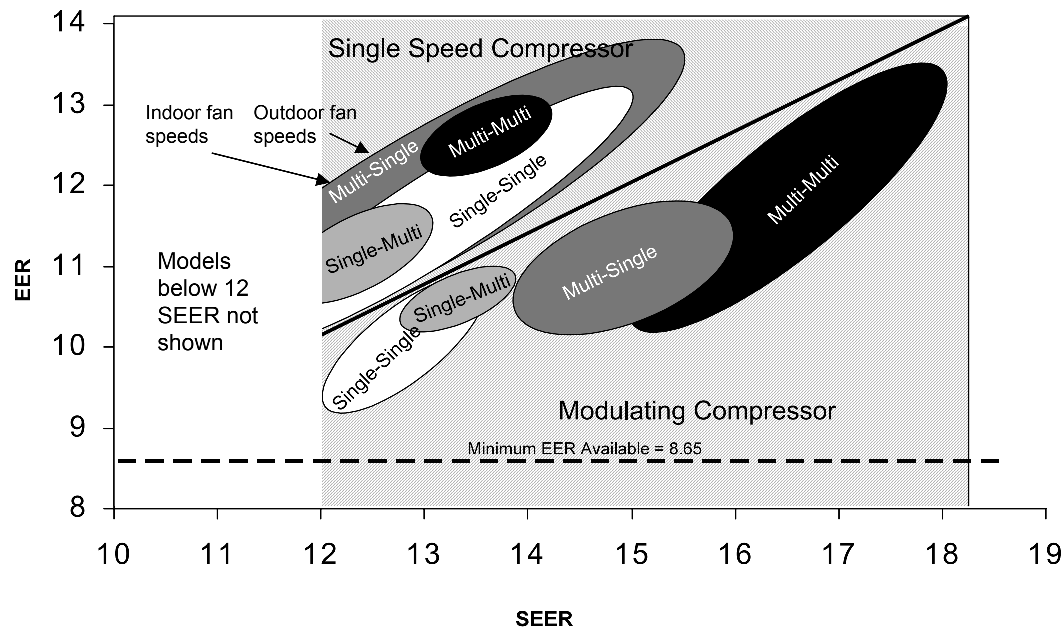
Since electricity generation, transmission, and distribution capacity is determined by the electrical load served during these peak demand times, products that demonstrate improved efficiency under peak conditions can reduce the need for added electrical system capacity. The utilities and environmental advocates also believe that reducing peak demand is an important component of any integrated plan to improve the reliability of the nation's electrical system. Recently there have been several well-publicized blackouts and brownouts following, or in the midst of, hot periods. Advocates of an EER-based standard believe that a SEER-only standard does not guarantee the desired improvement in peak-period performance.

4.9.1 Current Relationship between SEER and EER

It is certainly true that SEER is not an ideal indicator of system efficiency in very hot weather, and SEER may not be the best indicator of the seasonal efficiency for equipment operating in the warmest regions of the country. However, the relationship between efficiency at 82°F and at 95°F is fairly close for single-speed, single-capacity equipment, which represents the vast majority of unitary equipment in the marketplace. For other equipment, including variable or multi-speed equipment or equipment with modulating capacity, the 82°F test point is given a great deal of weight in determining the SEER rating. In these cases, the relationship between SEER and EER(95°F) is less certain, and manufacturers have some flexibility and incentive to improve SEER without improving EER(95°F).

The SEER test, representing equipment performance over the entire cooling season, encourages manufacturers to design equipment that consumes less energy throughout the cooling season for the average user. The EER(95°F) test, which is a measure of steady-state performance under only one set of climatic conditions, cannot provide insight into cyclical performance or cooling efficiency at cooler temperatures which represent the bulk of the cooling season nationwide.

Figure 4.6 shows the relationship between SEER and EER in available 3-ton split air conditioners based on three factors: 1) whether the compressors are single speed/capacity or modulating, 2) whether outdoor fans are single or variable speed, and 3) whether indoor fans are single or variable speed. Each oval represents a particular combination of the three factors. No models with a combination of factors falls outside its oval.



Source: *ARI Unitary Directory*, February-July 1998

Figure 4.6 Effects of Compressor and Fan Modulation on the EER-SEER Relationship in Existing 3-ton Split Air Conditioning Systems

The graph shows a clear division between models based on whether they possess modulating compressors. The models with the highest SEER ratings have modulating compressors (this includes systems with multiple compressors, variable speed compressors, and variable capacity compressors.) This suggests that, all else equal, a system with a modulating compressor will achieve a SEER boost of 2-4 points or will suffer an EER loss of up to 2 points.

Manufacturers have some leeway in designing the SEER-EER relationship. Systems with modulating compressors are typically optimized for low capacity operation to boost SEER[g]. This can reduce the performance of the system at high capacity. Sensible heat ratios (dehumidification) and sound levels can also suffer. Since the efficiency standards and the market are tied to SEER ratings, manufacturers have the incentive to boost SEER at the expense of EER. Notice, however, that totally modulating systems can attain the same EER ratings as their single speed counterparts. That indicates that manufacturers can design and produce high efficiency, totally modulating systems that boost both EER and SEER.

[g] The DOE SEER test procedure for modulating systems gives weight to the operating efficiency at low-capacity and an outdoor dry bulb of 82°F.

The graph also suggests a few conclusions about the indoor and outdoor fans. First, the SEER and EER impacts of modulating indoor fans is greater than the impacts of outdoor fans. Second, modulating compressors cannot achieve their greatest SEER and EER benefits unless both the indoor and outdoor fans are also modulating. Third, systems with efficient single speed compressors do not receive much of a boost in either SEER or EER by virtue of the presence of variable speed fans.

Clearly, a higher SEER standard will not guarantee a proportional increase in EER. As time progresses, thermodynamic limitations make it more expensive to squeeze additional efficiency from a system. At the same time, advances in control and power technologies reduce the cost of incorporating the modulating capabilities that allow manufacturers to boost SEER without raising EER.

4.9.2 The Effect of Refrigerant Choice on EER and SEER

Refrigerant also plays a role in this issue. 410A is less efficient than both HCFC-22 and 407C at high condenser temperatures, but more efficient at low condenser temperatures. The difference between 410A and 407C is on the order of 5 percent at the EER rating points. 410A can result in improved SEER ratings and reduced EER ratings. Equipment manufacturers will be encouraged to adopt 410A for its SEER effect, but utilities may prefer 407C for its EER effect.

4.9.3 Options for Possible EER Standards

The Department has at least four options for ensuring that EER(95°F) performance is maintained under new SEER standards. First, the Department could rely on the physical relationship between EER(95°F) and SEER to ensure that an increase in SEER would result in a corresponding increase in EER. The Department is not aware of any modulating, multi-speed, or variable speed air conditioners (hereafter referred to collectively as modulating equipment) being offered below 13 SEER, and very few of the available 13 SEER products are modulating equipment.

The second option would be to establish an EER(95°F) floor that must be met by modulating equipment only or, alternately, all equipment.

The third option would be to establish a minimum EER requirement at each SEER level, even for products exceeding the minimum SEER level. Again, this could be established for modulating equipment only or for all equipment.

The fourth option would be to alter the SEER test procedure to rely more on 95°F performance and less on performance at cooler temperatures. This would provide incentive for manufacturers to optimize their designs to favor the warmer part of the cooling season and warmer regions of the country.

The first option, relying on the current relationship between EER and SEER, would provide no assurance that manufacturers would not develop and promote equipment in the long term that would seriously reduce EER ratings. The fourth option, altering the SEER test procedure to favor higher temperatures, would require a new rulemaking to establish new procedures as well as a full revision to the analysis supporting this rule to incorporate the new SEER values.

Both the second and third options, mandating minimum EER ratings, would guarantee that products under new standards would achieve the same EER ratings as they do today without altering the test procedures. The third option is more aggressive since it would require that products of higher SEER ratings must also meet increasingly stringent EER ratings.

Within the second and third options, the Department could establish EER requirements of varying degrees of stringency. For example, it could select EER levels equivalent to the ratings of the minimum EER rating of available equipment today at the proposed standard level, the median EER rating, anywhere in between, or even higher.

A serious concern regarding the third option and EER standards higher than the minimum EER ratings available today is that both would discourage the development and sale of modulating capacity and variable speed equipment. Modulating equipment realizes a benefit in the SEER test, allowing manufacturers to reduce the cost of the core components compared to non-modulating equipment. This cost reduction partially offsets the cost of the modulation, making modulating equipment more affordable for consumers. Being required to meet the same EER standards as non-modulating equipment would negate this cost benefit.

Consumers value the added benefits of modulation, and manufacturers realize this value in the form of higher revenues. For consumers and the nation, modulation mitigates the inefficiencies caused by oversizing the system during installation. Oversizing is a widespread problem that causes frequent equipment cycling, increasing energy consumption. Furthermore, oversizing arguably contributes more to peak power demand than does any reduction in EER associated with modulating equipment.

4.9.4 EER-SEER Relationship in Current Equipment

To help to determine what the appropriate EER(95°F) requirement might be for each of the four classes, Table 4.27 shows the EER rating for models at each decile within a SEER level. The data source is the *ARI Unitary Directory.* We considered only NAECA-covered products below 66,000 BTU/hr intended for domestic sale. Each SEER level includes all products from the nominal SEER level through those rated 0.2 SEER higher than the nominal level (e.g. 10 SEER through 10.2 SEER). We considered only coil-only models where possible. The data includes all models available, not only the High Sales Volume models subject to DOE certification. The Table also provides the number of models included in the dataset in each category.

Table 4.27 Distribution of Energy Efficiency Ratios (EERs) in Residential Unitary Products

	Nominal Efficiency (SEER)							
	10	11	12	13	10	11	12	13
Decile	Split Air Conditioners (RCU-A-C)				Packaged Air Conditioners (SP-A)			
0%	8.5	9.4	9.1	9.7	8.3	9.2	10.0	10.1
10%	9.0	9.8	10.5	11.2	8.7	9.5	10.3	10.1
20%	9.1	9.8	10.6	11.4	8.8	9.6	10.4	10.5
30%	9.2	9.9	10.7	11.5	8.9	9.8	10.4	10.9
40%	9.3	10.0	10.7	11.5	9.0	10.0	10.5	11.0
50%	9.3	10.0	10.8	11.6	9.1	10.1	10.5	11.0
60%	9.4	10.2	10.9	11.7	9.2	10.2	10.5	11.0
70%	9.5	10.2	11.0	11.8	9.3	10.3	10.6	11.0
80%	9.5	10.4	11.0	11.8	9.4	10.5	10.7	11.1
90%	9.6	10.6	11.2	12.0	9.6	11.0	10.8	11.4
100%	10.8	11.4	12.8	13.0	10.7	11.2	11.0	11.5
Number	5133	2809	4156	901	446	146	157	50
Decile	Split Heat Pumps (HRCU-A-C)				Packaged Heat Pumps (HSP-A)			
0%	7.4	9.3	8.6	9.6	8.2	9.0	9.8	11.0
10%	9.0	9.6	10.3	11.1	8.7	9.2	10.0	11.0
20%	9.1	9.7	10.4	11.3	9.0	9.3	10.1	11.0
30%	9.1	9.9	10.5	11.5	9.0	9.5	10.2	11.0
40%	9.2	10.0	10.6	11.6	9.0	9.5	10.3	11.0
50%	9.3	10.0	10.7	11.9	9.1	9.7	10.4	11.0
60%	9.4	10.2	10.8	12.3	9.2	9.9	10.5	11.6
70%	9.5	10.3	10.9	12.3	9.4	10.0	10.6	12.0
80%	9.5	10.5	11.0	12.4	9.5	10.0	10.8	12.0
90%	9.6	10.7	11.4	12.5	9.6	10.0	11.0	12.0
100%	10.8	12.0	12.7	13.7	10.5	10.2	11.5	12.0
Number	2538	1408	2147	452	443	96	306	7

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